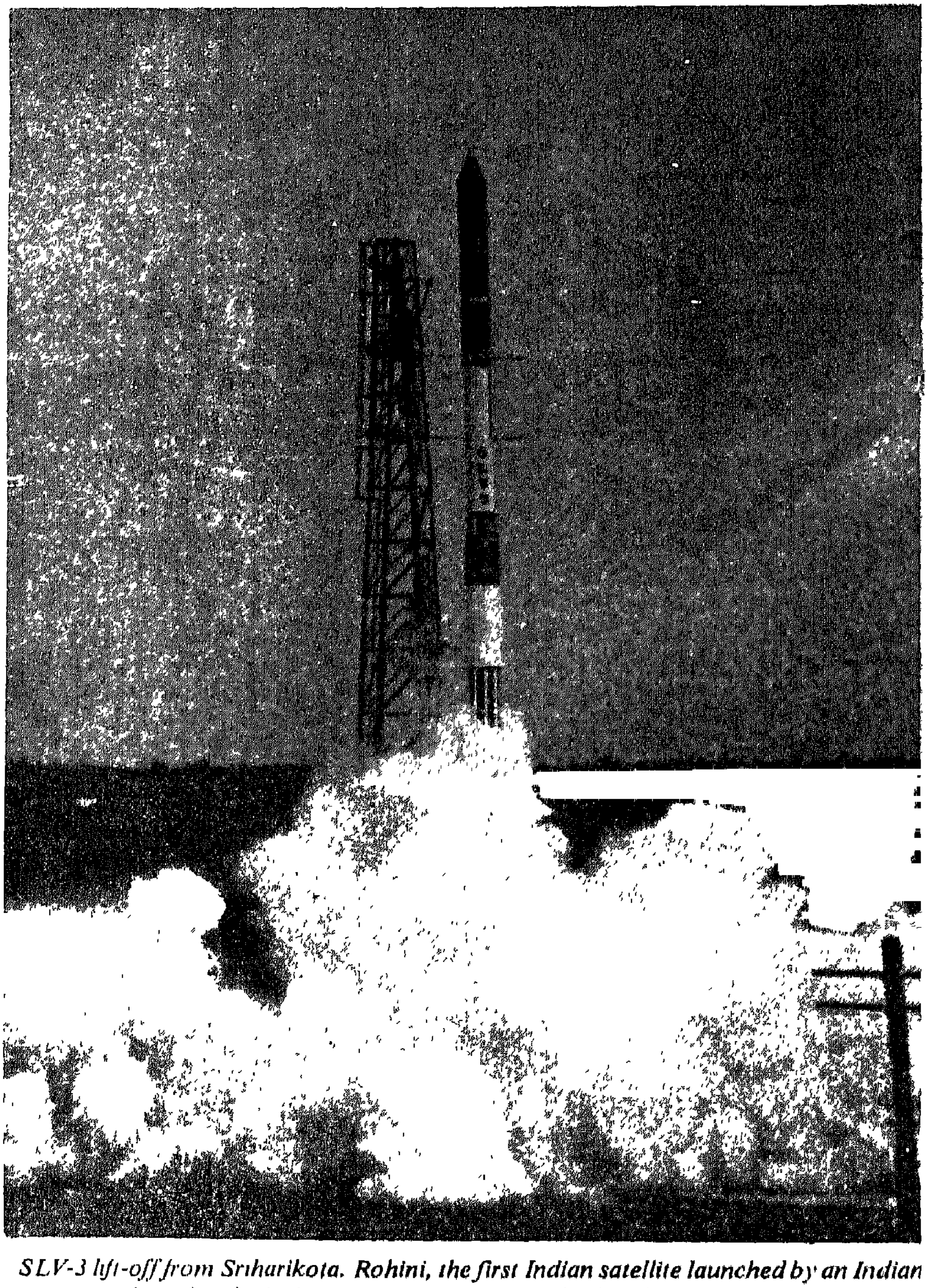
PHYSICS

A TEXTBOOK FOR SECONDARY SCHOOLS

PART I



SLV-3 lift-off from Sriharikota. Rohini, the first Indian satellite launched by an Indian launch vehicle from the Indian soil, was orbited by the SLV-3.

PHYSICS

A TEXTBOOK FOR SECONDARY SCHOOLS

PART I

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राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद्
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(*Courtesy*: Press Information Bureau)

A photo-montage of different stages of the solar eclipse from start (2.42 p.m.) to the end (4.59 p.m.) on 16 February 1980, with the Konark Sun Temple in the background. The 'total eclipse' started at 3.54 p.m. and lasted for about two minutes.

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Foreword

THE NATIONAL POLICY on Education adopted by the Government of India laid great emphasis on making the study of science an important part of the curriculum. According to this policy, science should be taught on a compulsory basis to all pupils as a part of general education during the first ten years of schooling. Accordingly, a textbook in physics for Classes IX and X was developed and published by the National Council of Educational Research and Training (NCERT) in 1975. This book was recommended by the Central Board of Secondary Education (CBSE) for the schools following their syllabus.

The *Ten-year School Curriculum—A Framework*, published by the NCERT in 1975, provided broad guidelines for developing a new set of textual materials in science for Classes IX and X under the 10+2 pattern of schooling. Keeping in view the guidelines provided by the Framework, a textbook in physics for Classes IX and X was developed by the NCERT through an Editorial Board, and published in 1977.

Curriculum development is an on-going process. A new physics textbook for secondary classes was prepared by the CBSE through their Committee of Courses and a national workshop. The NCERT subsequently collaborated with the CBSE in this effort for curriculum revision in order to prepare textbooks which could serve as models for other Boards as well. A National Seminar-cum-Workshop on Secondary Science and Mathematics Curriculum was thus organised in March 1984 to review the syllabi and draft textual materials with a view to provide suggestions and guidelines for their improvement. The authors, in collaboration with the Physics Group of the Department of Education in Science and Mathematics, revised and finalised the textual content in the light of the suggestions made during the National Seminar-cum-Workshop. The present textbook in physics is an outcome of these efforts and is meant for Class IX of the schools following the syllabi of the CBSE.

In this textbook, an effort has been made to link physics with everyday life situations. Another feature of this book is that a section on practical work has been included, which provides for the students some guidelines on the practical work that they are expected to do. It is hoped that this will encourage good practical work by students.

The National Council is thankful to the Central Board of Secondary Education, particularly

to the Chairman, Fr. T.V. Kunnunkal and the Director (Academic) Dr. K.D. Sharma, for initiating this process of curriculum revision in physics, for providing inputs—both expertise and materials—to the National Seminar-cum-Workshop, and for active collaboration throughout the development of this new textbook. Special thanks are due to Prof. L.S. Kothari, Convener, Committee of Courses in Physics, as also to the authors and to the participants of the National Workshop. I must also express my gratitude to Prof. A.K. Jalaluddin, Joint Director, NCERT, and Prof. B. Ganguly, Head of the Department of Education in Science and Mathematics, who have borne much of the burden in organising the revision of the science syllabi and the preparation of the new textbooks. The members of the Physics Group of the Council's Department of Education in Science and Mathematics, who helped in the revision of the material and who saw the book through the press, deserve all appreciation and thanks.

Suggestions for further improvement of the book will be most welcome.

P.L MALHOTRA
Director
National Council of Educational
Research and Training

New Delhi
8 January 1985

Preface

IN 1981, THE Central Board of Secondary Education (CBSE) decided to abolish courses 'A' and 'B' in the natural sciences and introduce one single course for all students. The Committees of Courses in the three sciences - physics, chemistry and biology - then decided to get the new textbooks written under their guidance. This idea was supported by the Chairman, CBSE. With the constant support and encouragement of Father T.V. Kunnunkal, Chairman, CBSE and Dr. K.D. Sharma, Director (Academic), CBSE, this task has now been completed for Class IX.

Since the end of 1983, some experts from NCERT have also been deeply involved in this endeavour. The constant and enthusiastic support of Dr. P.L. Malhotra, Director, NCERT is most gratefully acknowledged. We are also thankful to Professor A.K. Jalaluddin for his constant help.

Before the preparation of the manuscript, draft syllabi for Classes IX and X were drawn up and circulated to representative schools in Delhi The comments received from teachers were very valuable and we would like to thank them for their interest and cooperation.

The writing team, consisting of Dr. V.S. Bhasin, Dr. L.S. Kothari and Dr. S.P. Tewari of Delhi University and Shri R. Joshi, Professor K.J. Khurana and Dr. R.N. Mathur of the NCERT, prepared the first draft of the manuscript for Class IX. This was reviewed by two National Workshops, one organised by the CBSE and the other by the NCERT. The hard work put in by the participants is greatly appreciated. Most of the suggestions made at these workshops have been incorporated in the final version of the textbook. Some members of the writing team also visited a few schools and held discussions with the students and teachers there. These discussions were very valuable for the preparation of the text. Apart from the members of the writing team, Professor Ved Ratna and Professor C. Singh of the NCERT were also involved in finalising the manuscript. Shri R. Joshi, Professor K.J. Khurana and Professor Ved Ratna were mainly responsible for seeing the book finally through the press. They put in a lot of hard work, and their effort is greatly appreciated. Professor B.B. Tripathi of the Indian Institute of Technology, Delhi, readily agreed to go through the final manuscript and his comments and suggestions are gratefully acknowledged.

We would also like to thank the Indian Institute of Astrophysics, Bangalore, for the photographs of the stars and the comet; the National Physical Laboratory, New Delhi, for the photograph of the prototype kilogram; and the Indian Space Research Organization, Bangalore, for the photograph of the launching of the Satellite Launch Vehicle (SLV-3).

The authors would welcome suggestions and comments from students and teachers using this book.

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Professor of Physics
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and
Convener
CBSE Committee of Courses in Physics

New Delhi
26 December 1984

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C.B.S.E.'s Participant

17. Sh. K.S. Chacko, Asstt. Secretary, Central Board of Secondary Education, New Delhi.

NCERT's Participants

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20. Dr R.N. Mathur, DESM, NCERT, New Delhi.
21. Prof Chhotan Singh, DESM, NCERT, New Delhi.
22. Prof. Somnath Datta, R.C.E., Mysore.
23. Prof. Ved Ratna, DESM, NCERT, New Delhi.

Contents

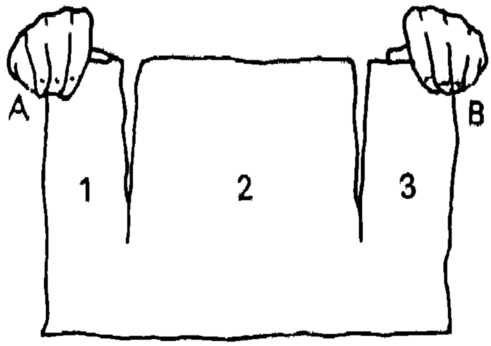
Introduction

THE WORD 'SCIENCE' literally means knowledge. In a broader sense, it implies a systematic study of nature. For our convenience, we have divided science into several branches like physics, chemistry, zoology, botany, etc. Even mathematics forms a part of science. But we must realise that there is no such division in nature. Any phenomenon we observe in nature is usually very complex and can be understood as a whole only, when we consider it from all possible angles.

Rapid advance in science became possible when Galileo (1564-1642) invented the 'experiment'. An experiment is a situation or a phenomenon involving a small number of parameters (or variables) so that their influence on the phenomenon can be studied systematically. Hence the great importance of experimentation in science, particularly in physics.

The study of science can be great fun, provided we approach it in the right spirit and devote some time to it. If you enjoy chess or football or hockey or any other game, you must have first learnt to play it and then practised it for long. Similarly, if you want to enjoy science you must learn some of the basic rules, and what is more important, practise what you learn. Science is not confined to the classroom or within the specified periods of the time-table. Science can be learnt at all times and at all places. At night, watching stars and planets and studying their motions is science. During the day, watching birds, animals and plants and trying to understand their behaviour is science

Science does not study animate objects only. Even inanimate objects like air and water have many interesting properties for us to study. What is more, even abstract things like numbers have their own identities and possess some interesting properties. For example, take the Goldbach Conjecture. According to this, every even number can be written as a sum of two primes (e g., $20 = 7 + 13$, $36 = 13 + 23$ or $48 = 7 + 41$). You may find it very strange that this simple conjecture has not yet been proved, while at the same time no example contradicting this conjecture has been found.



In physics also you can perform many meaningful, simple and baffling experiments. Take a piece of paper, 5×3 cm^2. Make two cuts as shown. Hold end A in one hand and end B in the other. Now pull the hands apart either by jerk or slowly (as you like) in such a way that the paper divides into three separate

pieces 1, 2, and 3. If you do not succeed the first time, try again or ask your friends.

The best way to learn physics is to try experiments yourself. Since you are now in a fairly senior class, we expect that you will also be interested in knowing why a particular experiment works and you will learn its significance. For this you must know the language of physics. The first few chapters of the book (except the first) have to be taken in this light. How can we converse if we do not know the language?

The main fascination of physics arises from the fact that in spite of the tremendous progress made in this field in this century, we are still far from understanding nature in any depth. What man has achieved is really remarkable. By studying the extremely feeble light coming from a distant star we can know its temperature, its chemical composition, its distance from us and many other things. With the invention of Laser (a special kind of source of light) we can measure the distance of the moon from the earth within a fraction of a centimetre and can obtain three-dimensional photographs of objects. Yet we know little about gravitation, about the ultimate constitution of matter and about time. As history of science, particularly of this century, reveals, there are most unexpected discoveries being made every now and then and nature seems more mysterious than ever. Science will hold a deep and almost mystic fascination for all those who develop a taste for it.

This book begins with a chapter on stars. You must develop star watching as one of your hobbies. It is enjoyable, useful and is not likely to interfere with your other activities. The next chapter is on measurements. We have given a lot of data here (and also in some other chapters) to impress upon you that distances, masses, etc., of objects that are not directly accessible can also be measured. Do not try to commit them to memory. They are not meant to be asked in the examination. The next five chapters deal with different aspects of motion and the basic language of physics. Learn carefully the precise meaning of the words. In physics we use common words but to some of these we give a new and precise meaning. Eighth chapter deals with heat and temperature. You are already familiar with the basic concepts; here we make them a little more quantitative.

In Class IX it is expected that you will learn some of the basic terms of physics and also learn to converse about problems of physics. You should also do some suggested activities and simple experiments. These experiments may be divided into two categories: (i) those that you should perform outside the classroom, preferably at home, and (ii) those involving some basic measurements that you should perform in school. Both are equally important.

The last section deals with practical work. It is to help you in getting some practical training in carrying out basic measurements. Here we have introduced some activities. They are simple and must be performed by every student.

CHAPTER 1

Watching the Night Sky

THERE IS NO spectacle more grand than the sky on a clear, dark night. Since time immemorial, people have watched the sky with wonder and interest. Our ancestors made very careful observations of the motions of the sun, the moon and other heavenly bodies and could predict eclipses and other astronomical events much before people in the West learnt to do that. This became possible because of their discovery of zero and the principle of place value of writing numbers.

Our climate is moderate throughout the year and the number of clear nights in a year is also very large. Night sky watching can be fascinating and this is one area in which those of you living away from big cities can be at an advantage. In big cities, strong lights and atmospheric pollution combine to produce a background illumination against which one can observe only the bright stars.

1.1 The Night Sky (Celestial Sphere)

It is better to begin a serious watch of the sky on a clear, dark, moonless night. (Your mother, or better still, your grandmother, who is most likely to be conversant with the lunar calendar, will guide you as to when the moon will not be visible in the early part of the night.) You must first sit in a relaxed position at a fairly open place or on the roof for a few minutes, without looking at bright lights. By doing so your eyes will get accustomed to seeing in darkness. You may now stand up or watch the sky from your relaxed position, fixing the top of a tree or any other reference mark. You will see many stars, some rather bright and some just visible. General estimate is that at any one time, on a clear moonless night, one can see about 2000 stars with naked eyes.

If you watch the sky for an hour or more, or you watch it around the same time on different nights, you will find that the stars change their respective positions in the sky. They appear to revolve round the earth They travel from east to west, rising in the east and setting in the west. If you observe carefully, you will find that their relative positions do not change except for the relative positions of five star-like objects which are visible to the naked eye and which travel through the sky without twinkling. These are known as the 'wanderers' or the planets.

The whole view appears as if inside a very large sphere, tiny lights were permanently fixed at different points, and we were situated at the centre of this sphere. We call this sphere the Celestial Sphere. This imaginary sphere appears to rotate round the earth from east to west. This apparent motion of stars is due to the rotation of the earth round its axis from west to east. To us the earth appears stationary and the various bodies in the sky like the sun, the moon and the stars appear to move in the opposite direction. Since the earth completes one rotation in 24 hours, to us it appears as if the Celestial Sphere (Fig. 1.1) completes one rotation in the same time. The axis of rotation of the Celestial Sphere is the same as the axis of rotation of the earth. By carefully watching the night sky, we can locate this axis.

Look towards the north. Imagine a line in this direction which makes an angle equal to the latitude of the place (Table 1.1 gives the latitude of some cities) with the horizontal plane (horizon) at the point where you are standing as shown in Fig. 1.2. This is the axis of rotation.

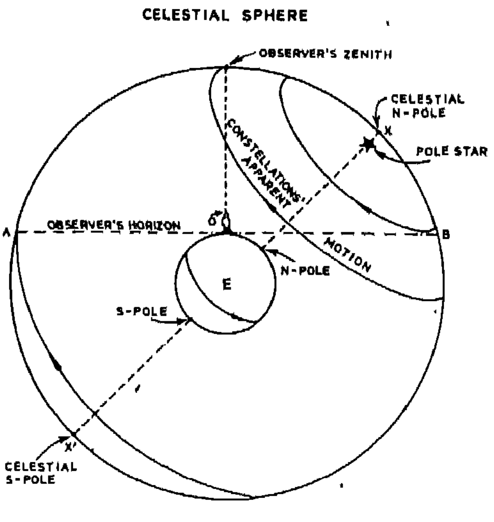


Fig. 1.1: *A view of the Celestial Sphere. O is the observer. The dotted line AB is the observer's horizon. Line XX' is the axis of rotation of the earth. Arcs represent the path followed by the stars as viewed from the earth. Note that the direction of rotation of the earth and that of the Celestial Sphere are different*

Fig. 1.2: *Angle θ between the observer's horizon along the north and the direction of the Pole Star is equal to the latitude of the place.*

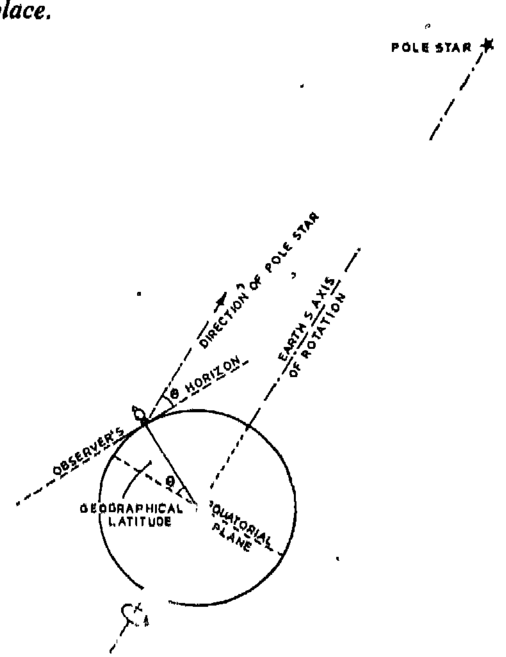


TABLE 1 1: **Latitude of Some Places (Rounded off to Nearest Degree)**

City	*Latitude*	*City*	*Latitude*
Ahmedabad	23°	Jabalpur	23°
Allahabad	25°	Jaipur	27°
Aurangabad	20°	Jodhpur	26°
Bangalore	13°	Lucknow	27°
Belgaum	16°	Madras	13°
Bhopal	23°	Nagpur	21°
Bhubaneswar	20°	Pune	19°
Bombay	19°	Patna	26°
Calcutta	23°	Raipur	21°
Chandigarh	31°	Shillong	26°
Cuttack	20°	Simla	31°
Delhi	29°	Srinagar	34°
Gauhati	26°	Trivandrum	8°
Hyderabad	17°	Ujjain	23°
Indore	23°	Varanasi	25°
		Waltair	18°

As the earth revolves round the sun in its orbit, the direction of this axis does not change and remains fixed in space throughout the year. It is a pure coincidence that in the northern hemisphere in which we live, a particular star marks fairly precisely the position where the axis of rotation of the earth cuts the Celestial Sphere. This star is called the Pole Star or the 'Dhruva Tara'. The word pole is derived from the Greek word 'Polos' which means pivot. 'Dhruva' also means steadfast or unchanging. As this star is the 'pivot' of the axis of rotation, to us it appears fixed, unlike other stars. (There is no such star in the southern hemisphere to mark the point where the other end of the axis cuts the Celestial Sphere.) This is clear from Fig. 1.3 which is a long-time exposure of the stars around the Pole Star. As we move away from the Pole Star, the star trails become longer. All stars in this picture have moved through the same angle. But larger the distance from the centre, bigger is the arc. It will also be clear from Fig. 1.3 that stars lying close to the Pole Star are always visible, i.e., they are always above the horizon, during whichever season or at whatever time of the night we observe them (also see Fig. 1.2). They are the ones that lie within a cone of angle equal to the latitude of the place with the axis of the cone along the direction of the axis of rotation of the earth. Stars lying outside this cone will appear to rise in the east and set in the west like the sun or the moon.

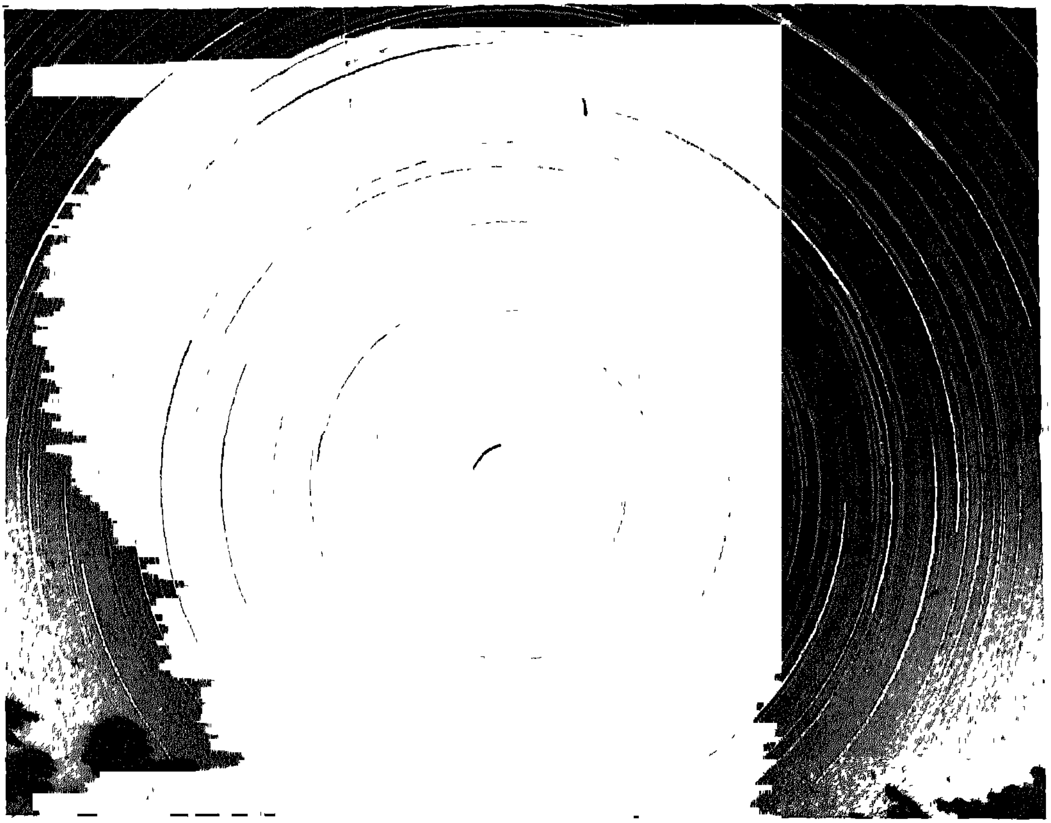
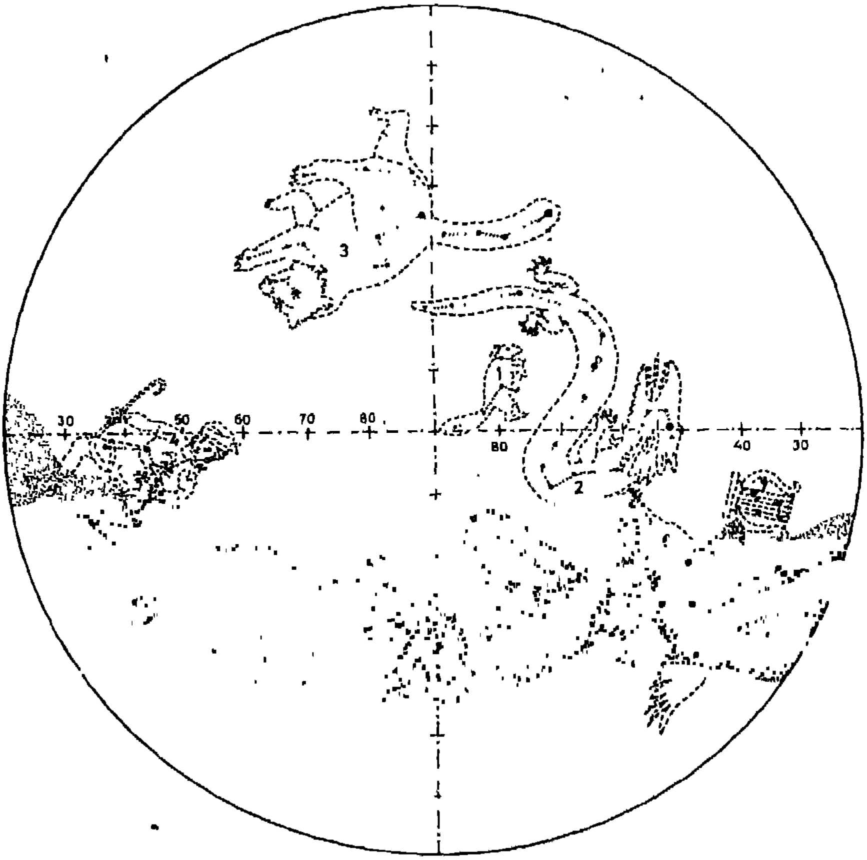


Fig. 1.3: *Long time exposure photograph of stars around the Pole Star. The straight track is that of a 'meteor' In this picture, the Pole Star is the arc closest to the actual Celestial North Pole, the 'pivot' of the earth's axis.*

Courtesy: Indian Institute of Astrophysics

1.2 Constellations

Another thing you will readily discover as you watch the night sky is that the relative positions of the different stars do not change at all. Over the ages, people have seen likeness of different objects, particularly animals, in different star groups; these groups are now called *constellations*. Each constellation has been assigned a name signifying an animal or an object it appears to resemble. A few of the prominent constellations are shown in Fig. 1.4. Ursa Major means 'Great Bear' and Ursa Minor stands for 'Little Bear'. In Fig. 1.5 are shown separately these two 'Bears' and the associated stars. Similarly, certain figures are associated with all other constellations You should learn the star positions for different constellations, because only



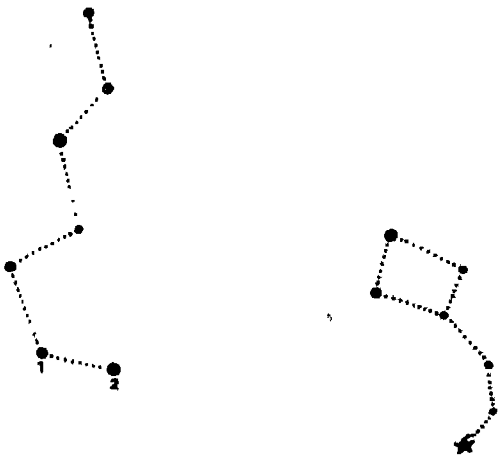


Fig. 1.4: *(a) A night-sky map showing some prominent constellations (with their representative imaginary shapes) around the Celestial North Pole: (1) Ursa Minor (Little Bear or 'Dhruva Matsya') (2) Draco (Dragon or 'Kaleya') (3) Ursa Major (Great Bear or 'Saptarshi') (4) Auriga (Charioteer or 'Sarathi'). (5) Cassiopeia ('Sarmishtha') (6) Cygnus (Swan or 'Hansa') and (7) Lyra ('Svara-Mandala'). The shaded region is the Milky way.*

Fig. 1.5: *Constellations Ursa Major and Ursa Minor shown separately. These are seen close to the Pole Star.*

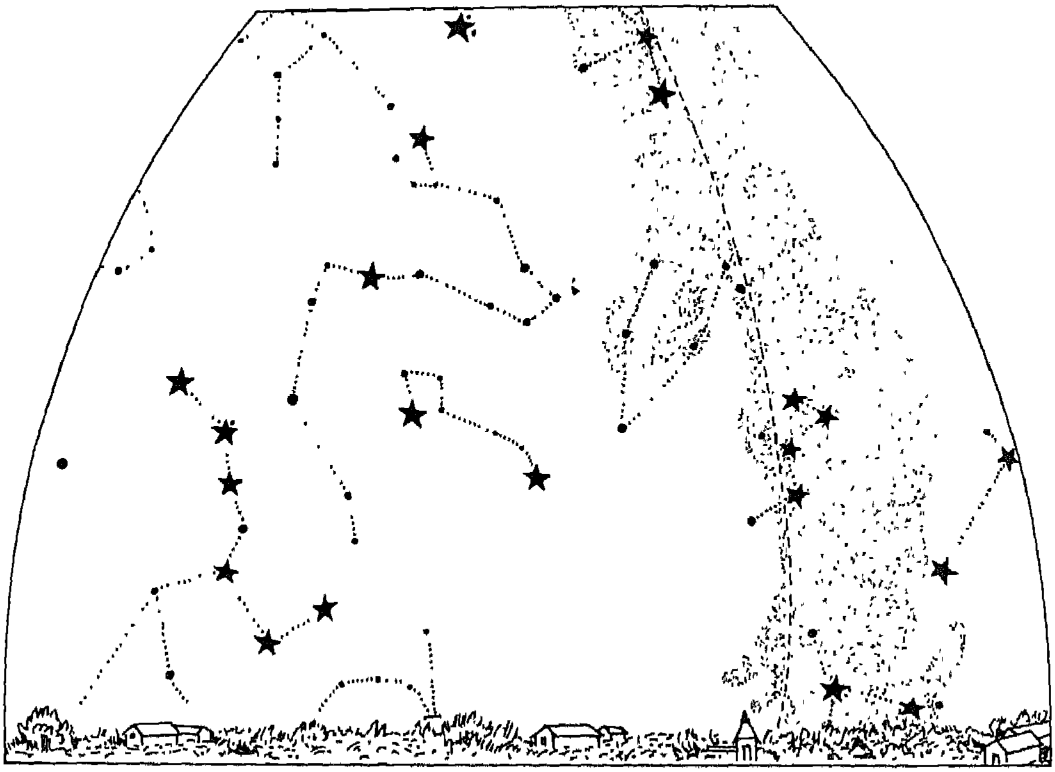


Fig. 1.6: *Mid-September view of a part of the northern hemisphere for latitude 25° N around 8.00 p.m.*

then you will be able to identify them in the sky. Fig. 1.6 is a star map of a part of the northern section of our hemisphere. You find another star map in Fig 1.7 showing several constellations which can be seen in the night sky during the year. Try to identify the different constellations in this map and learn their relative positions.

If you watch the night sky around the same time on different nights, you will find that the star patterns advance by about 30° each month. Thus, the stars that you observe in a given direction will be different in different seasons. Therefore, you must orient the star map properly depending upon both the time of observation and the season.

Suppose it is the month of September and you want to observe the stars around 9 p.m. Lie down on the roof on your back looking up. Hold the map (Fig. 1.7) facing you and orient it in such a way that 'September' lies towards the south. The map then represents the star positions as they would appear in the sky. For every hour beyond 9 p.m., you must rotate the star map anti-clockwise by 15°. For times earlier than 9 p.m., turn the map clockwise for every hour. You will have noticed that in this map the Pole Star is located at the centre. When you actually observe the sky, the Pole Star will be around 30° above horizon at Delhi. Therefore, in the

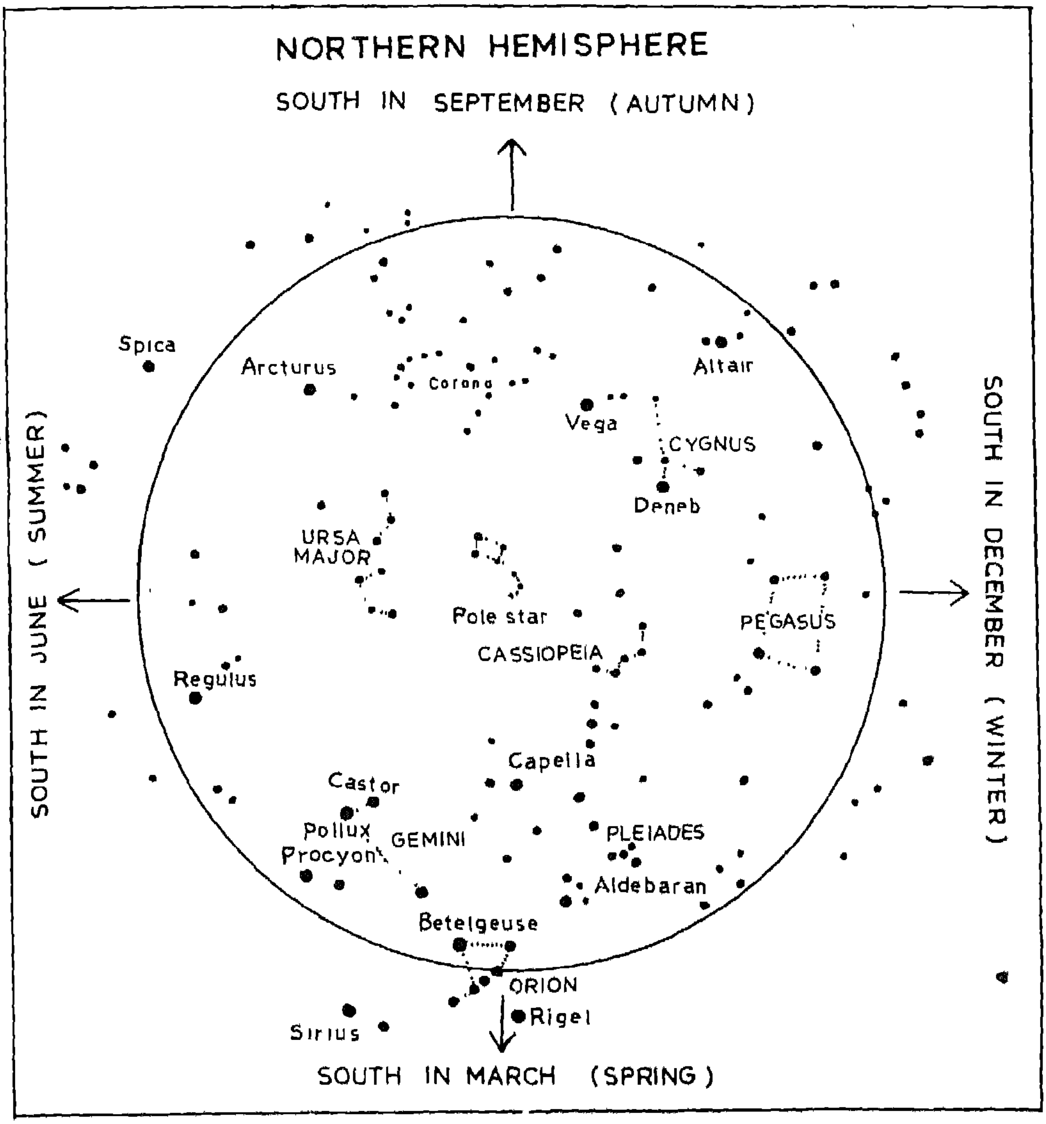


Fig. 1.7: *A star map of the northern hemisphere.*

northern sky you will see only those stars of the map that are close to the Pole Star. On the other hand, in the southern sky you will see more stars than are shown in the map.

During winters 'Orion' is a very prominent constellation. It is also easily recognised by the three stars that lie close to each other in a line. The brightest star in the sky, 'Sirus', lies close to this constellation. During spring and summer, Ursa Major is above the horizon in the early part

of the night. During autumn, Ursa Minor and Cassiopeia are easily visible. You should learn to identify these and other constellations in the night sky.

Of particular interest now is the constellation 'Lyra'. Observations made with the help of space satellites indicate that the brightest star in this constellation, 'Vega', may have planets going round it. If these observations are confirmed, Vega will become the second star in the universe, the first one being our sun, around which planets have been discovered.

It is more enjoyable and also simpler if you watch the sky in the company of a few friends who are also interested in this activity (and if possible request a person conversant with the night sky to help you initially). Many newspapers publish star maps sometimes in the first week of the month. You should cut these out and use them to identify more constellations.

1.3 Pole Star

You can easily learn to identify the Pole Star. If you have a magnetic compass, you can locate the north with fair accuracy. Otherwise, knowing the direction from which the sun rises, you can identify the north In this direction, look at an elevation above the horizon of about 30°, if you are in or around Delhi. If you live in another town or village, look up Table 1.1 to find the latitude of your place or the place nearest to yours. The elevation of the Pole Star above the horizon will be the same as the latitude of the place. Around this position, you should see a star of average brightness. There are no other clearly visible stars in its immediate neighbourhood. To identify it more precisely, you look in its neighbourhood for the constellation Ursa Minor. These are seven stars in the form of a kite with a thread tied at one corner. At the end of the 'thread' is the Pole Star (Figs. 1.4 to 1.7). Having identified Ursa Minor, you should then try to identify Ursa Major and 'Cassiopeia'. Ursa Major also appears like a kite with a thread. In this case, if you extend the line joining stars 1 and 2 (Fig. 1.5) then it will point towards the Pole Star.

Star watching has some practical uses as well. One can determine the north during the night by identifying the Pole Star. By studying the apparent motions of the stars in the night sky, astronomers can tell the exact time.

1.4 Planets

We mentioned earlier about the planets, which appear like stars and yet are not stars. Out of the nine planets of the solar system, five are clearly visible to the naked eye (Fig. 1.8). 'Venus' is the brightest object in the night sky, leaving out the moon. It is visible either in the early morning in the eastern sky or in the early evening in the western sky. 'Mercury' is also fairly bright but can be seen just after sun-set in the west or just before sun-rise in the east. 'Mars' appears a little reddish, 'Jupiter' and 'Saturn' along with Mars can be seen to traverse the whole circle like other stars (unlike Mercury and Venus). The simplest method of identifying planets from stars is that the stars twinkle, whereas planets do not. Also the relative position of the planets keeps changing slightly night after night in relation to the stars. Newspapers and magazines publishing the night sky maps also give the positions of the planets. *Science Reporter* (a monthly journal of the CSIR, New Delhi) gives this information in some detail. You should learn to identify the planets.

In many of our big cities planetaria have been built. Here they simulate the motion of the

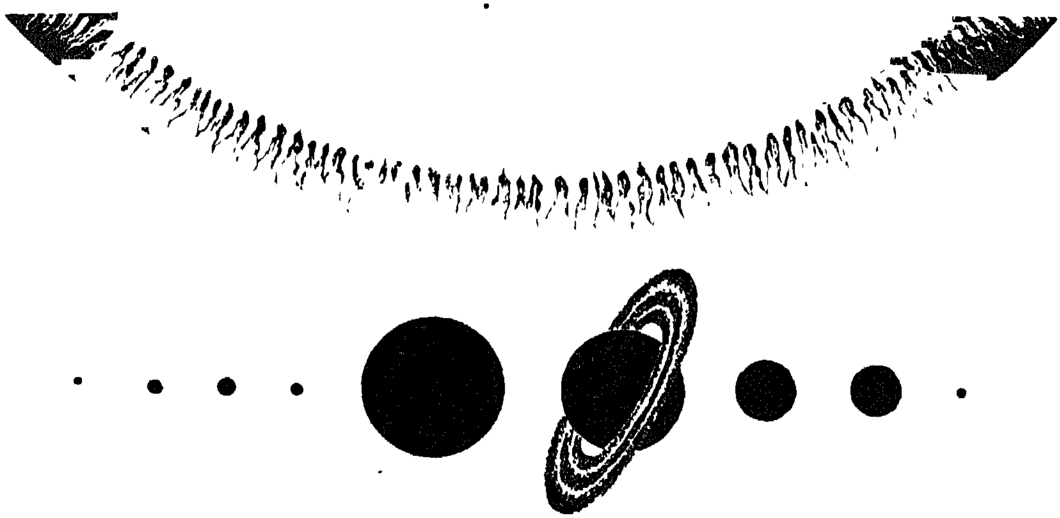


Fig. 1.8: *The nine planets in their order of distance from the sun. (A part of the sun is also shown.) Left to right: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto. Only five of the planets (Mercury, Venus, Mars, Jupiter and Saturn) can be seen with the naked eye.*

stars and the planets on the inside of a large dome. If you get a chance, you must make it a point to visit a planetarium.

Maharaja Jai Singh (1680-1734) of Jaipur got built five huge astronomical observatories, one in Delhi and others in Jaipur, Mathura, Ujjain and Varanasi. Now these are not much in use, because of the greater accuracy obtainable with telescopes. But when these observatories were built these were considered as very accurate. You should visit them, if at any time you happen to be in any one of these cities.

1.5 Other Objects in the Sky

Besides stars, planets and the moon, there are other objects which one can occasionally see in the night sky. These are comets, meteors and artificial satellites.

1.5.1 *Comets:* These are members of the solar system and journey round the sun as the planets do. However, their period of revolution round the sun is usually very large. They appear as a bright head with a long tail (Fig. 1.9).

The tail always points away from the sun. A few comets appear every year but they are usually very faint and are visible only through powerful telescopes. Once in many years one gets a chance to see a comet with the naked eye. Halley's Comet with a bright head made its last apperance in 1914. The next chance will come in 1986 when Halley's Comet should again be visible.

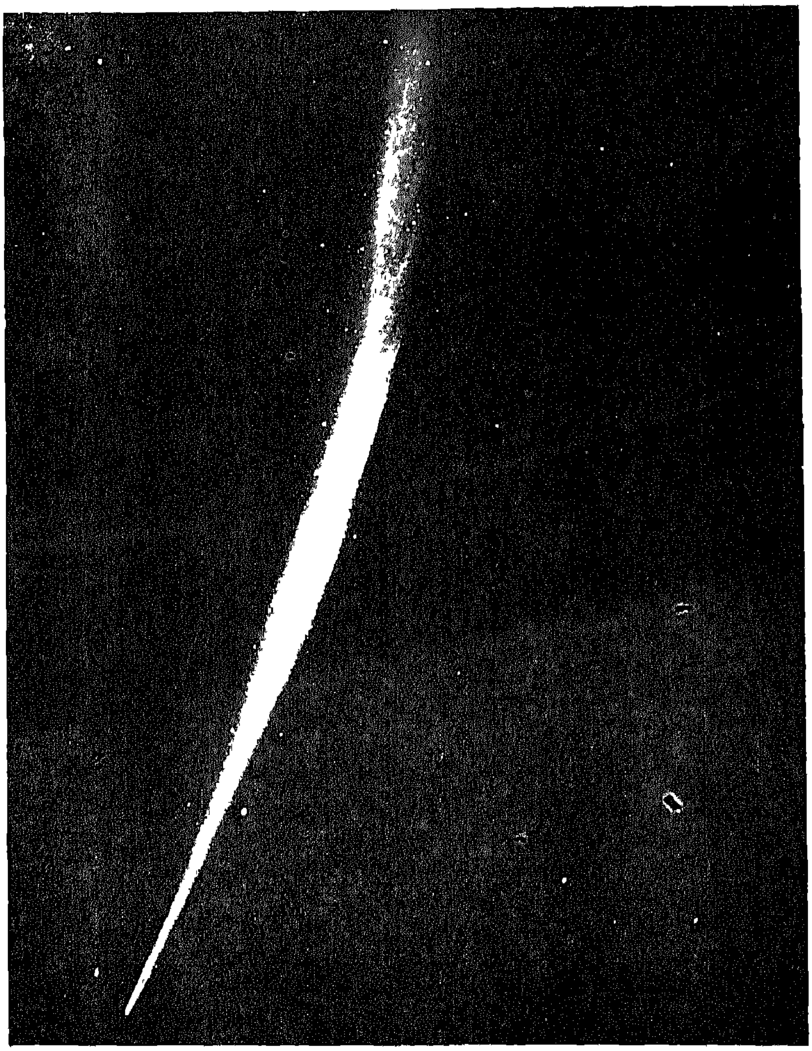


Fig. 1.9: *A Comet*

Courtesy: Indian Institute of Astrophysics

1.5 2 *Meteors:* Meteors or 'shooting stars' are stony or metallic bodies, mostly of very small size, which become visible when they travel through the earth's atmosphere. Due to friction of air, they heat up to very high temperatures and are completely vaporized much before they can reach the ground. The bright straight streak in Fig. 1.3 is a meteor track. Occassionally a part of a large meteor may survive the journey and reach the earth. We call this a *meteorite*.

1.5 3 *Artificial Satellites:* A number of man-made satellites, including a few put in orbit by our country (the first one being Aryabhata), are revolving round the earth. (They will ultimately burn like meteors.) Just before sunrise or just after sunset, they may be seen travelling across the sky at a fairly fast pace.

ACTIVITIES

1. Learn to identify the Pole Star and some prominent constellations such as Great Bear ('Saptarshi'), Orion and Cassiopeia.
2. Many newspapers besides *Science Reporter* (a monthly magazine of the CSIR) publish star charts and the positions of the different planets. With the help of such charts learn to identify the planets visible to the naked eye besides the [illegible] stars and constellations.
3. If possible, visit a planetarium or an astronomical observatory [illegible] place. Try to find out about the different 'instruments'

QUESTIONS AND PROBLEMS

1. What is the distinction between stars and planets?
2. How would you locate the 'Pole Star'? Mention, step by step, the process you will follow.
3. What distinguishes Pole Star from other stars? Where is it located in the sky?
4. What is a 'comet'? Name the prominent comet expected to be seen in early 1986.
5. (a) Explain what is a meteor.

   (b) Can a meteor reach the earth's surface? Justify your answer.
6. Explain what you understand by the terms 'constellation', 'star', 'planet' and 'satellite'. Classify the following under these heads:

   Pole Star, Great Bear, Saturn, the Moon, the Sun, the Earth and Orion.

CHAPTER 2

Measurements

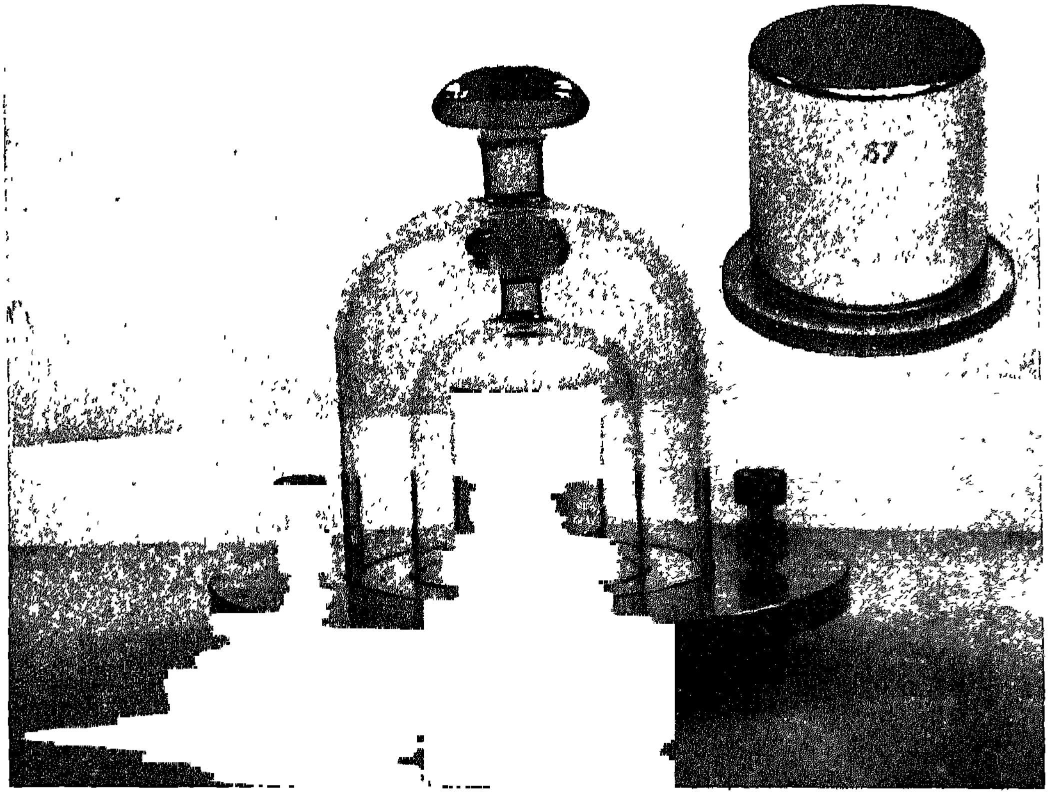
PHYSICS IS A science based on measurements. The importance of measurement has been emphasized by Lord Kelvin (1824–1907), one of the outstanding physicists of recent times, in the following words:

> "I often say that when you can measure what you are speaking about and express it in numbers, you know something about it, but when you cannot measure it and when you cannot express it in numbers, your knowledge is of....... unsatisfactory kind, it may be the beginning of knowledge, but you have scarcely...... advanced to the stage of science...."

Measurement of a physical quantity implies comparing it with the known amount of the same quantity. This known amount we call as *unit*.

In general we are free to take any quantity as a unit. For example, consider length. You can measure length in terms of your out-stretched palm or any other unit of your choice. The disadvantages of your choosing an arbitrary unit are obvious. Suppose, the breadth of your desk is 3½ times your pencil. This measurement has no meaning for others, as they do not know the length of your pencil. Such a difficulty can be avoided, if we all decided to use the same unit of length called a *standard unit*. Standard unit of a quantity is fixed by definition and is accepted by all. For example, a 'metre' is standard unit for length and a 'kilogram' is standard unit for mass. For us in India, the National Physical Laboratory in New Delhi is responsible for

maintaining the national standards for all the basic units. The standard of mass is shown in the photograph.



Courtesy: National Physical Laboratory.

We will now study about the techniques of measurement of some basic physical quantities and the units associated with them.

2.1 Measurement of Length

When you say that the length of a room is 3.2 metres, it means that it is 3.2 times one metre. Here metre is the unit of length. For convenience, kilometre ($=10^3$ m) and centimetre ($=10^{-2}$ m) are also used as units.

Examine a few scales for measuring length, like the one in a geometry box, a tailor's tape and a cloth merchant's metre (Fig 2.1). Find the smallest division on each of these scales. The smallest division is called the *least count* of the scale. It is different for different scales. For example, the scale in the geometry box has a least count of 1 mm, whereas that of the cloth merchant's metre is 1 cm.

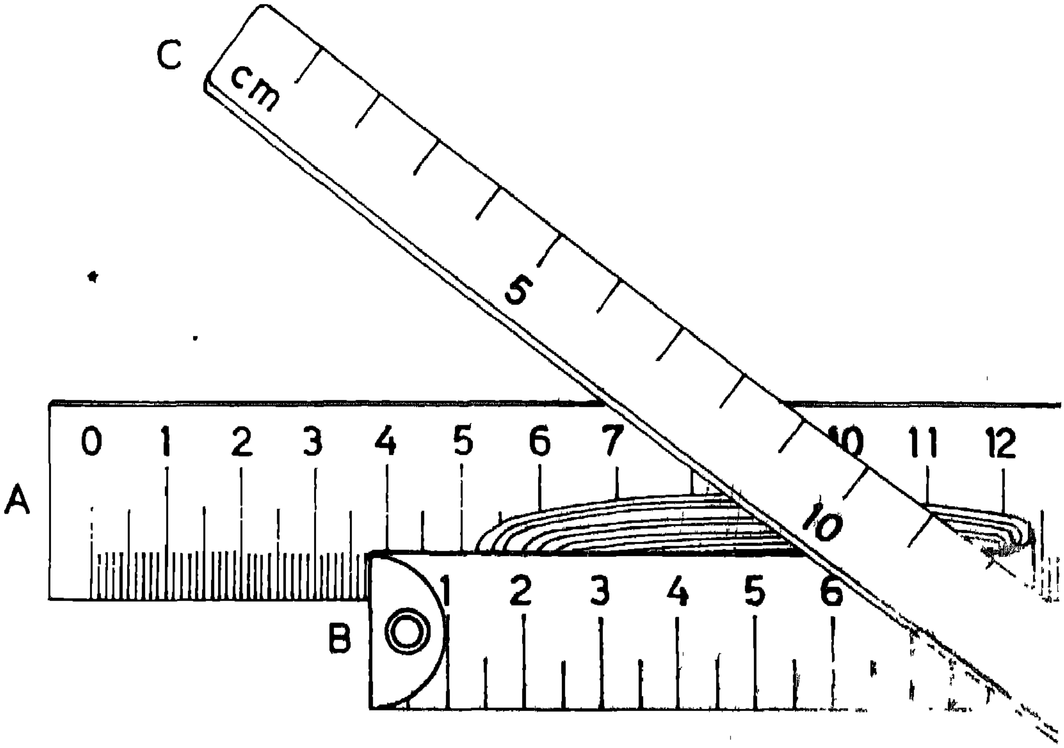


Fig. 2.1: *Three different types of scales used for measuring length.*

For measuring a certain length, we must choose our scale according to (i) the length we have to measure, and (ii) the accuracy with which it has to be measured. For measuring the diameter of a pencil, cloth merchant's metre would be a wrong choice and so would be the scale from your geometry box if we were to measure 20 metres of cloth.

In the science laboratory, we normally use a metre scale or a half metre scale. Least count of these scales is 1 mm. Here are the main points of care to be taken while measuring length:

Keep the scale along the length of the object, say, a postcard, and close to it as in Fig. 2.2-a. Let the left edge of the postcard coincide with a fixed mark on the scale, say 1.0 cm. (We avoid taking measurements from the 0-mark of the scale, because the corners of the scales are usually worn out.) You must check this with one eye closed and the other eye directly over the mark. Now, without disturbing the scale and the postcard, move your eye to the other edge of the postcard and read the scale (Fig. 2.2-a). Find the difference between the two readings to know the breadth of the postcard.

Eventhough you may be very careful in carrying out the measurements, some errors are

bound to arise The main sources of errors are·

(i) error in placing the scale (Fig 2 2-b), and

(ii) incorrect position of the eye while taking the reading (Fig 2.3-a, b)

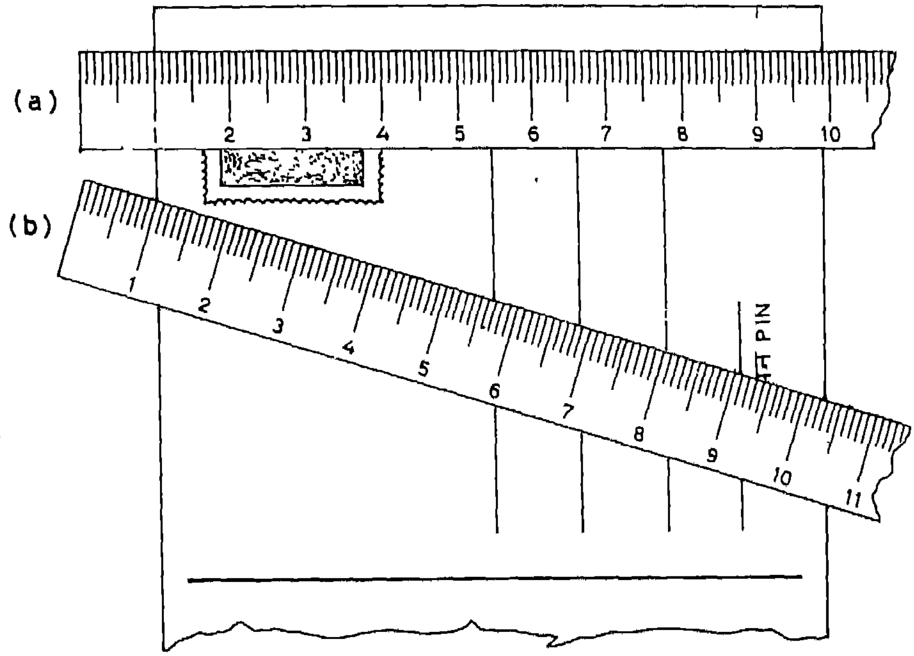
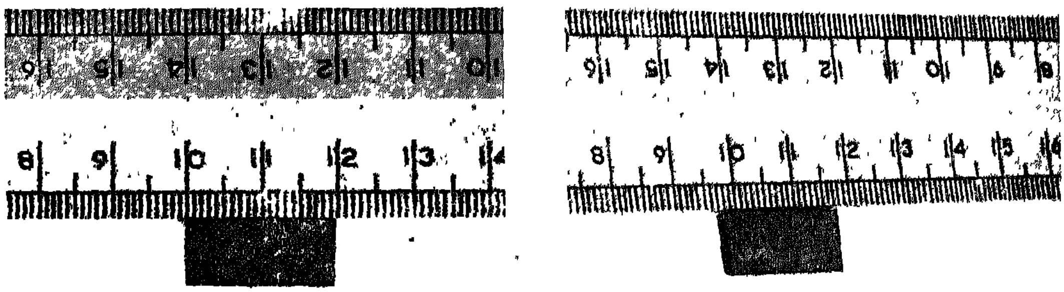


Fig. 2.2. (a): *Correct placement of the scale.*
(b): *Incorrect placement of the scale.*



(a) (b)

Fig. 2.3: *A view of the object and the scale as seen by the eye* **(a)** *just above left hand side of the object* **(b)** *somewhat inclined to the left.*

To reduce the error in our result, the measurement is repeated a number of times (say 5 times) and then the average is taken. To state the final result, we round off the digits immediately beyond the least count. The accepted procedure is to neglect digits beyond the least count if they are less than half the least count. If the digits beyond the least count are more than or equal to half the least count, we take it as one least count and increase by one digit the last significant figure. Let us take an example. Suppose the average length of an object comes to be 13.862 cm when measured with a scale having a least count of 1 mm Since the scale is capable of measuring down to 1 mm, i.e., 0.1 cm, digits beyond the first decimal place (62) have to be rounded off. Since 0.062 is greater than half the least count (0.05 cm), we round off 0.06 (6 is the last significant figure) to 0.1 cm. This is then added to 13.8 cm (here 8 is the last significant figure) to give a final result of 13.9 cm. On the other hand, if the average length of an object is 8.23 cm, we will round it off as 8.2 cm.

We should further note that the scales generally available to us are not very accurate in their graduations. If you collect a few common plastic or wooden scales and compare them (Fig. 2.4), this will become clear to you. The error in measurement due to incorrect graduations cannot be avoided by you at the present stage.

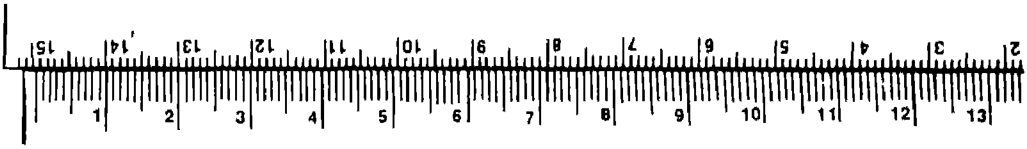


Fig. 2.4: *Comparing the graduations marked on two common scales from different manufacturers.*

Example 1: The table below gives a set of five observations for the length of a postcard taken with a scale having least count as 0.1 cm. Find the average length of the postcard.

Serial number	*Readings on the scale* *I*	*II*	*Length of the postcard (II—I)*
1.	1.0 cm	15.0 cm	14.0 cm
2.	1.0 cm	14.9 cm	13.9 cm
3.	5.0 cm	18.8 cm	13.8 cm
4.	10.0 cm	23.8 cm	13.8 cm
5.	10.0 cm	23.9 cm	13.9 cm

$$\text{Average length of the postcard} = \frac{1}{5} \times \text{(sum of lengths)}$$

$$= \frac{69.4}{5} = 13.88 \text{ cm}$$

Since the least count of the scale is 0.1 cm, we round off the result to 13.9 cm.

In some cases, we can use an indirect method for measurement. Suppose you want to measure the diameter of an office pin or of a thin metal wire. It is certainly not possible to measure the diameter of an office pin by direct measurement using a scale (Fig. 2.5). But if you

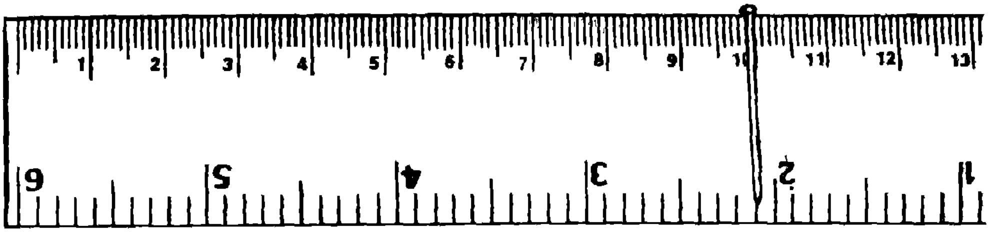


Fig. 2.5: *A view showing limitation of measuring the diameter of a pin using an ordinary scale.*

arrange several similar pins (say 15 to 20) close to each other, as shown in Fig. 2.6, and parallel to the graduations on the scale, you can find the length covered by the pins. Dividing this length

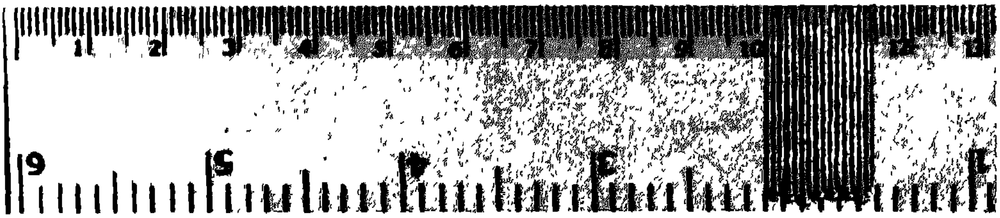


Fig. 2.6: *Set-up of the activity for measuring average diameter of a pin.*

by the number of pins gives the average diameter of the pin. (If you find any difficulty in keeping the pins from rolling, you can use a little plasticene or any other suitable adhesive to temporarily hold the pins in position.)

While measuring the length of an object, our eye can read scale divisions down to 1 mm. However, an estimation can be made up to half a millimetre. Below this, we cannot even estimate with our eyes. For measuring lengths with accuracy greater than 1 mm, we use special devices.

Suppose you measure the diameter of a glass marble using a scale, with least count of 1 mm, and two wooden blocks (Fig. 2.7). It comes to more than 1.9 cm, but less than 2 cm. To measure the diameter with a better accuracy, say to 0.1 mm, you need a device with a least count of 0.1 mm. Such a device is the *vernier calipers* (Fig. 2.8). For measuring lengths with still higher accuracy, down to 0.01 mm, another device called the *screw gauge* is used (Fig. 2.9). Both vernier calipers and screw gauge are described in the section on 'Practical Work'.

In most practical work, we come across lengths ranging from a few millimetres to a few

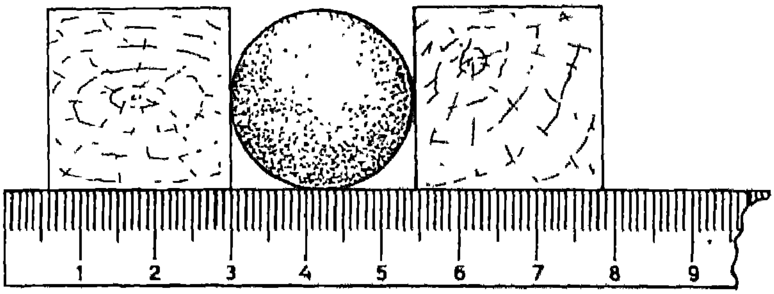


Fig. 2.7: *Measuring the diameter of a glass marble with the help of a scale and two wooden blocks.*

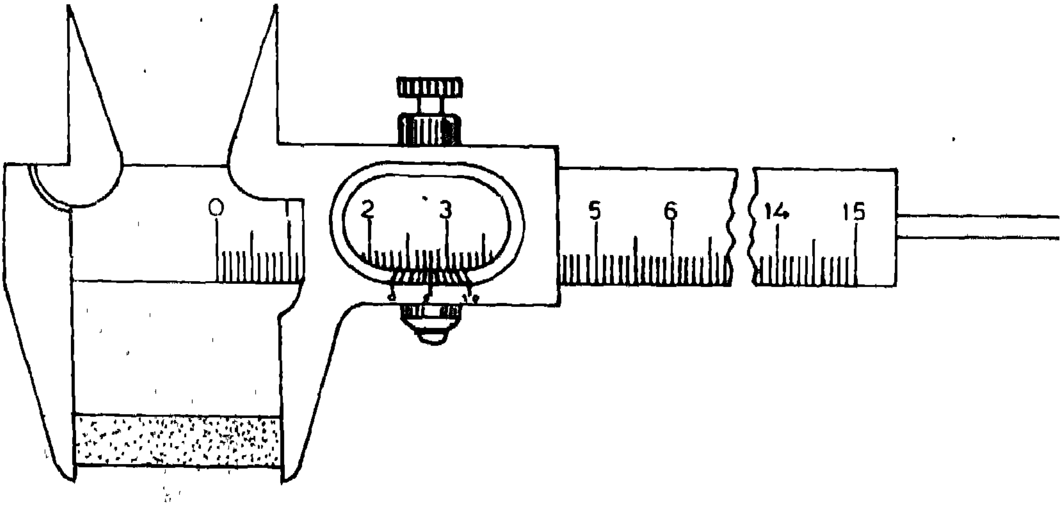


Fig. 2.8: *A vernier calipers*

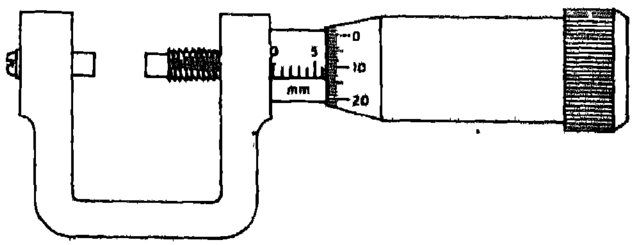


Fig. 2.9: *A screw gauge*

metres. However, in nature we encounter lengths which range from extremely small to astronomically large lengths. The diameter of the proton is about 10^{-15} m, while the farthest photographed heavenly object (a galaxy) is nearly 10^{25} m away. Fig. 2.10 gives some more typical distances within this wide range.

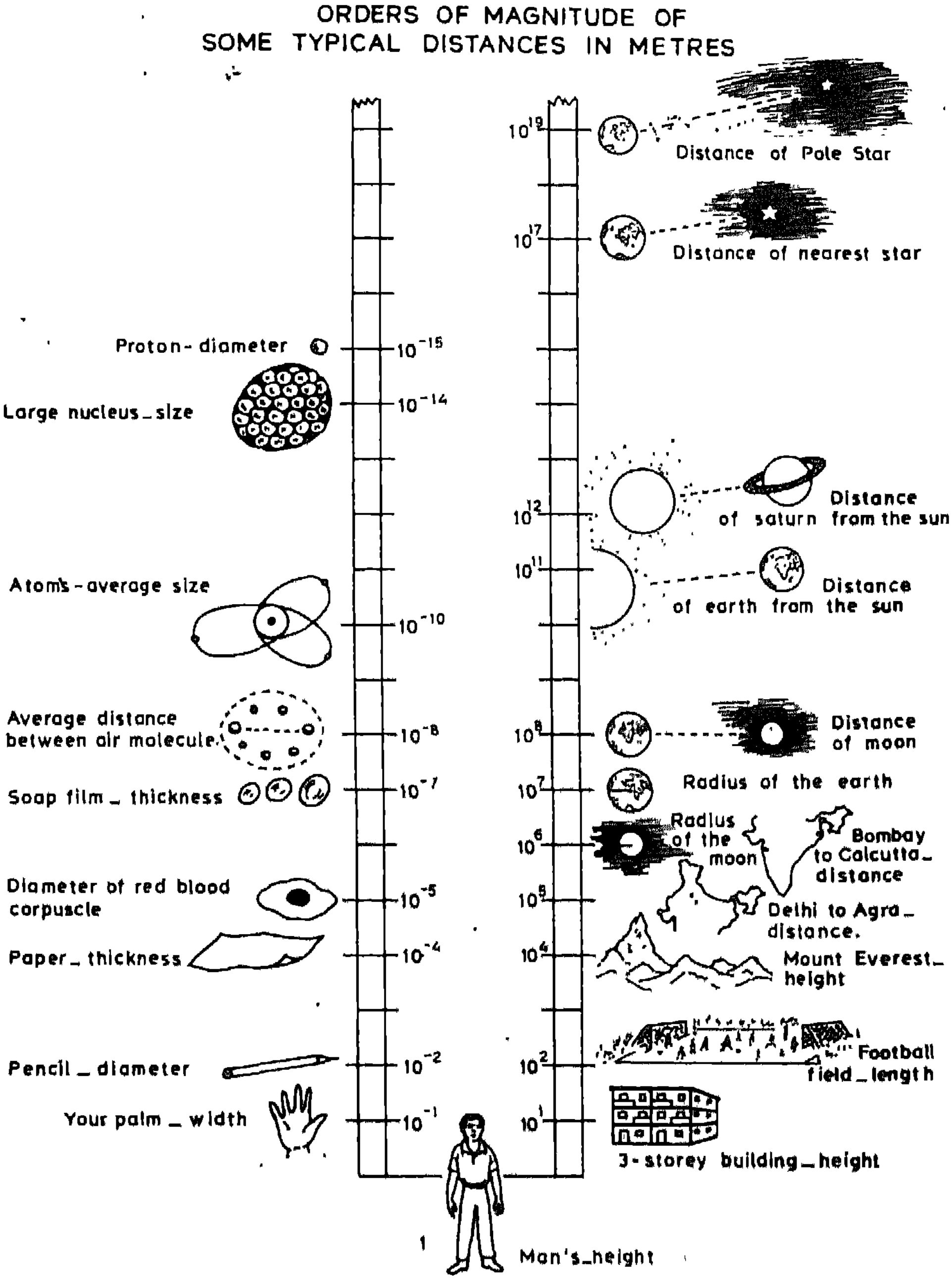


Fig. 2.10: *Orders of some typical distances in metres.*

The methods used for measuring distances in the different ranges are widely different. We note that often it is convenient to use multiples and sub-multiples of the metre to describe these distances. Some of the important ones are:

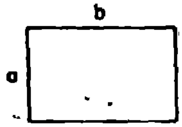
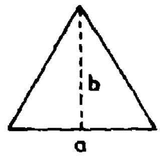
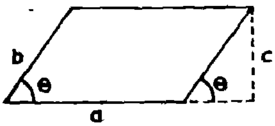
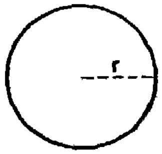
$$1 \text{ kilometre (km)} = 10^3 \text{ m}$$
$$1 \text{ centimetre (cm)} = 10^{-2} \text{ m}$$
$$1 \text{ millimetre (mm)} = 10^{-3} \text{ m}$$
$$1 \text{ Angstrom (A°)} = 10^{-10} \text{ m}$$

2.2 Measurement of Area

Consider your classroom. You cannot describe it by just giving one length. You need two measurements of length to describe the floor of the room. Given the length and the breadth, you can find its area. In geometry, you have learnt to find the area of other regular surfaces like a triangle, parallelogram or a circle (Table 2.1) We measure area in m².

Sub-multiples of this unit are cm² and mm². Multiple units like hectare (= 100m × 100 m) and km² are used for expressing large areas like those of land and water surface. As area is derived from two lengths, it is called a *derived physical quantity* and its unit is called a *derived unit.*

Table 2.1
AREA OF SOME FIGURES

FIGURE	AREA
	ab
	$\frac{1}{2}ab$
	$a.c$
	πr^2

Let us see how the area of an irregular surface can be found. Take a centimetre graph paper and place the surface on it. With the help of a pencil trace the outline of the body on the graph paper. Remove the body. Count the centimetre-squares falling completely inside the outline and note their number. Next consider those squares which are partly inside and partly outside the boundary. We count as full the squares which are more than half inside the boundary (marked 'a') and neglect the ones which are less than half inside the boundary (marked 'b') as shown in Fig. 2.11.

The total number of squares gives the area of the irregular surface in square centimetres. In case we desire to find the area with a greater accuracy, we must count the number of millimetre-squares.

We consider another aspect of the area. Take a rectangle of sides 3 cm by 2 cm. If we double each length, we will obtain a rectangle of sides 6 cm by 4 cm (Fig. 2.12). The area of this rectangle is 24 cm², which is four times the area of the original rectangle. This is a general result.

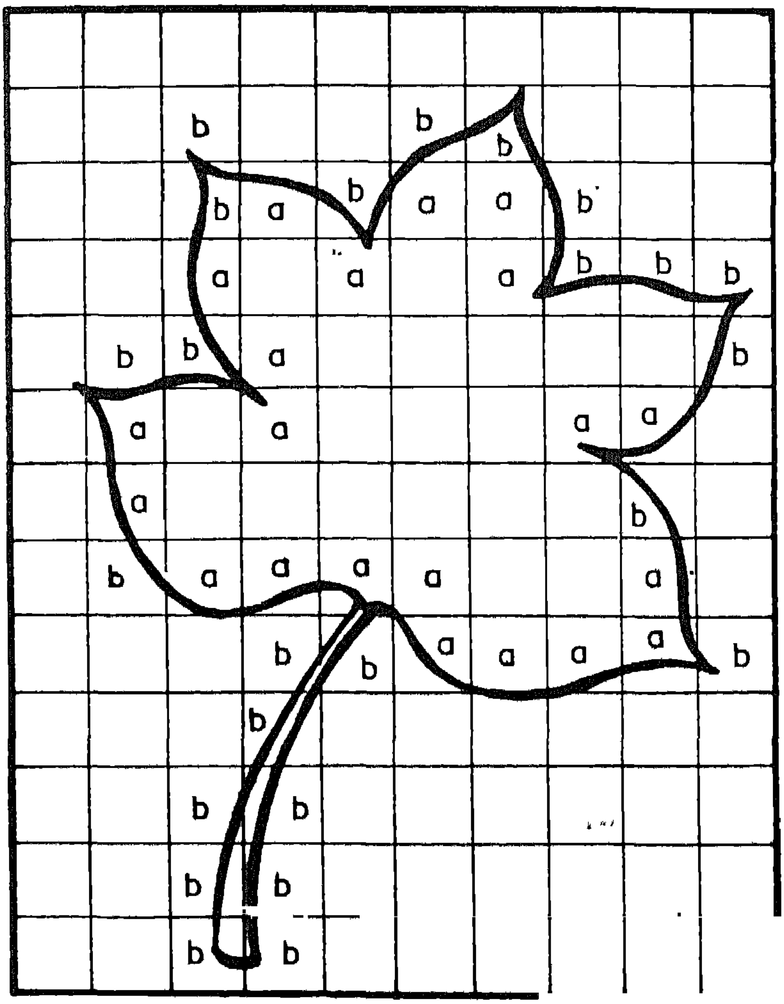
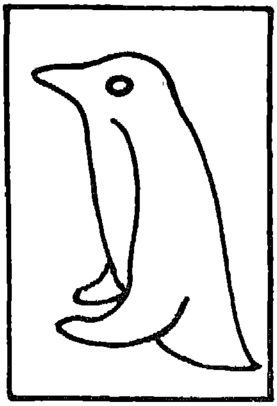


Fig. 2.11: *Area of an irregular body Squares marked 'a' are those which are more than half inside the boundary; squares less than half inside the boundary are marked 'b'.*



If for any given regular figure we increase all its sides n times, its area will increase n^2 times (Fig 2 12.) As a result of this we have the following conversions between m^2 and the other units used for convenience

$$1\ km^2 = 10^6\ m^2 \text{ and } 1\ cm^2 = 10^{-4}\ m^2$$

Fig. 2.12: *Area increases n^2 times if each side of a regular figure increases n times.*

Area need not be confined to a single plane. We can talk of the area of the walls or the total area of the room including its floor and ceiling. One can also talk of the surface area of a sphere and other regular bodies, like a cylinder. However, the surface area of an irregular body cannot be easily determined.

2.3 Measurement of Volume

Even the two lengths we talked about in the last section do not describe your classroom completely. One would like to know how high is the ceiling. Once you know the height of the ceiling, in addition to the length and breadth of the classroom, you can calculate its volume. The volume of a room is a measure of the space enclosed between the walls, the floor and the ceiling. It is a physical quantity different from length and area and like area is also a derived physical quantity. Its basic unit is m^3, which is a derived unit. Commonly used sub-multiples of this unit are:

$$cm^3 = 10^{-6}\ m^3 \text{ and } mm^3 = 10^{-9}\ m^3$$

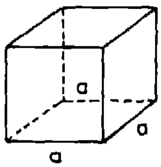
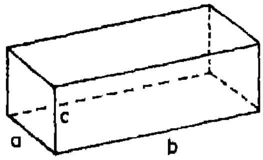
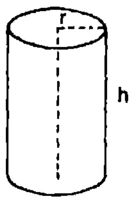
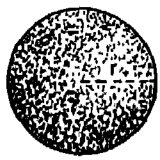
The multiple unit used for expressing large volume is km^3 = 10^9m^3

Volume of liquids and gases is expressed as capacity of the container holding them. The unit of capacity is litre

$$1 \text{ litre} = 10^{-3}\ m^3.$$

The commonly used multiples and sub-multiples are kilolitre = 1 m^3 and millilitre = 10^{-6} m^3

Table 2.2
VOLUME OF SOME SOLIDS

SOLID	VOLUME
	a^3
	$a\,b\,c$
	$\pi r^2 h$
	$\frac{4}{3}\pi r^3$

You already know how to calculate the volume of a regular solid body like a cube, a rectangular parallelepiped or a sphere (Table 2.2). To find the volume of an irregular solid body (insoluble in water) we use a graduated cylinder containing water. By putting the body in water and noting the change in water level, you know its volume (Fig. 2.13). If the body is a little bigger, an overflow can is used. The basis for this is the fact that the volume of the body is equal to the volume of the displaced liquid (Fig. 2.14).

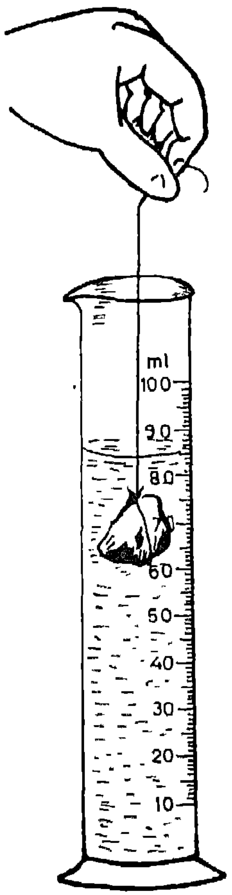


Fig. 2.13: *Use of a graduated cylinder to find the volume of a body insoluble in water.*

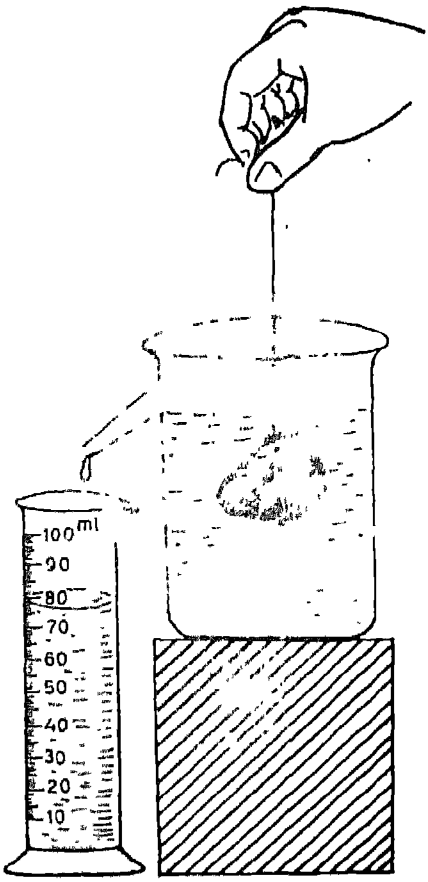


Fig. 2.14: *Use of an overflow can.*

Consider a cube of side 1 cm. If you quadruple each side, the volume of the cube will be 64 times the volume of the original cube. Thus, in general, if all dimensions of a regular solid body are increased n times, the volume of the body will increase n^3 times (Fig. 2.15).

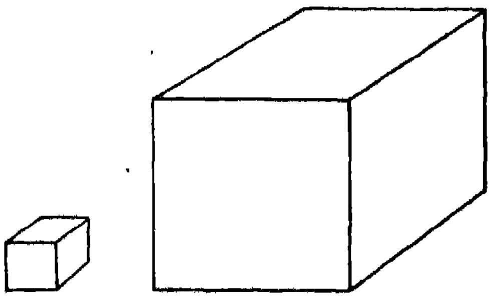


Fig. 2.15: *Volume increases n^3 times as each side of a regular solid increases n times.*

2.4 Measurement of Mass

You have perhaps used or seen in use a *spring balance* for measuring the weight of a body. Weight of a body is the *gravitational pull* (earth's pull) acting on the body. Pull of the earth is maximum on the poles and least on the equator If we could take the weight of the same body on the moon, it would be about 1/6th of the weight on the earth. This is because the pull acting on the body is 1/6 of the earth's pull. Thus weight of a body can change from place to place. However, we can define a quantity which does not change from place to place This physical quantity is called *mass*.

The quantity of matter present in a body is known as its *mass*. It is measured by comparing the given mass with an equal amount of known mass from a set of standard masses This is commonly done by using a beam balance and a set of known weights. However, when precise measurement of mass is required, more accurate balances and standard weights are used (Fig. 2.16) Basic unit of mass is kilogram, abbreviated as kg Its commonly used sub-multiples are gram ($1g = 10^{-3}$ kg) and milligram ($1mg = 10^{-6}$ kg).

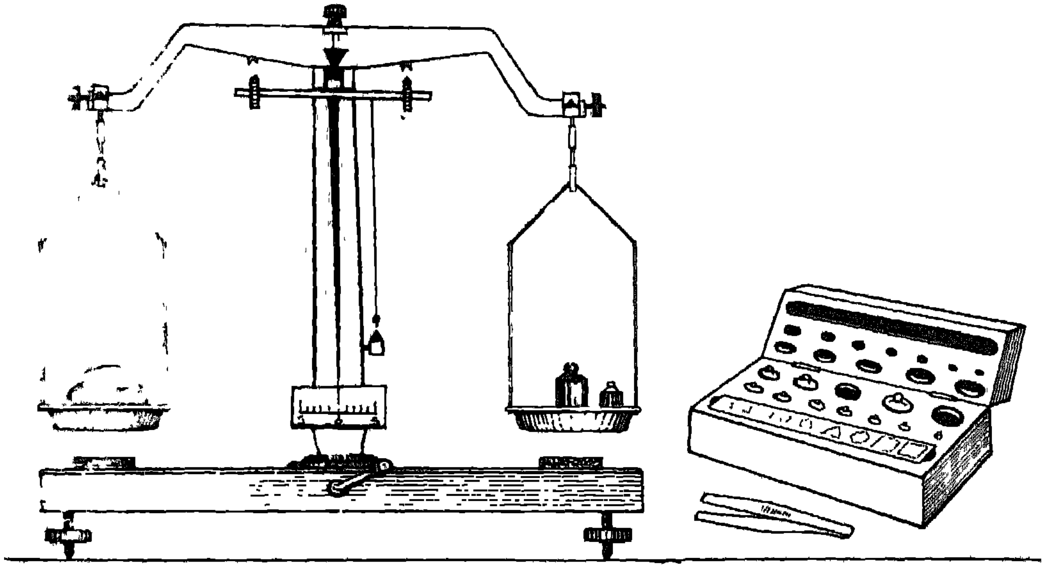


Fig. 2.16: *A physical balance with a weight box.*

[illegible] of length, in nature, we also observe a very wide range in the variation of [illegible] as the mass of an electron: 9×10^{-31} kg or as large as the mass of the sun: [illegible] 2.17 are given masses of some typical objects Widely different methods have [illegible] masses in the different ranges

ORDERS OF
SOME TYPICAL MASSES IN KILOGRAMS

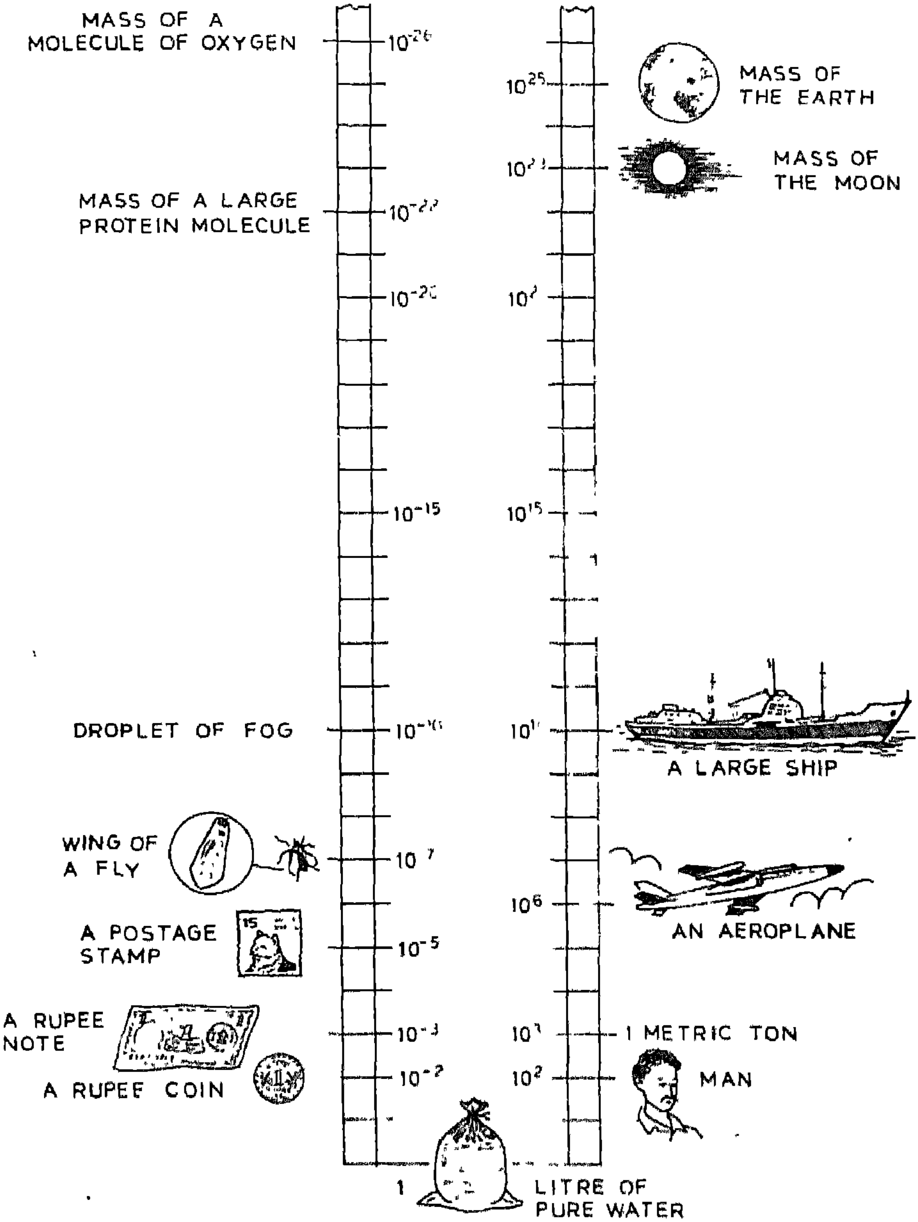


Fig. 2.17: *Orders of some typical masses in kilogram*

2.5 Measurement of Density

We can now define a *quantity* which is a characteristic of the material of a body. It is the *density*. Density is defined as mass per unit volume. If M is the mass of a body of volume V, then the density of the body ρ (Greek letter rho), is

$$\rho = \frac{M}{V}$$

Its unit is kg/m^3. Sometimes g/cm^3 ($= 10^3$ kg/m^3) is also used Densities of some common substances are given in Table 2.3.

TABLE 2.3: **Some Densities in kg/m^3**

The nucleus	10^{17}
Core of dense stars	10^8
Osmium	22.6×10^3
Gold	$19\ 3 \times 10^3$
Tungsten	19.3×10^3
Uranium	$19\ 07 \times 10^3$
Mercury	13.6×10^3
Steel	7.6×10^3
Human body (average)	1.07×10^3
Water pure	1×10^3
Ice	0.917×10^3
Cork	0.24×10^3
Liquid hydrogen	7.1×10^2
Room air	1.2

Another useful quantity is the *relative density*. It is the ratio of the density of a given substance and that of a standard substance. The standard substance is usually taken to be water. Therefore, we define relative density (r.d) as the density of the given substance, ρ_s divided by the density of water ρ_w

$$\text{r.d.} = \frac{\rho_s}{\rho_w}$$

For example, relative density of osmium, the densest element known, is 22.6. As r.d. is a ratio of the two densities, it is just a number without any unit.

2.6 Measurement of Time

You have to reach school 'in time' and for this you use a time-piece or a watch. A watch measures *time*. Basic unit of time is a *second*. In some cases like racing, short time-intervals

have to be measured accurately. For this a *stop-clock* (Fig. 2.18-a) is used. It can be started and stopped by pushing a lever (L). You can measure time accurately up to half a second with this For slightly more accurate measurements (up to 1/10th of a second), a *stop-watch* is used (Fig. 2.18-b)

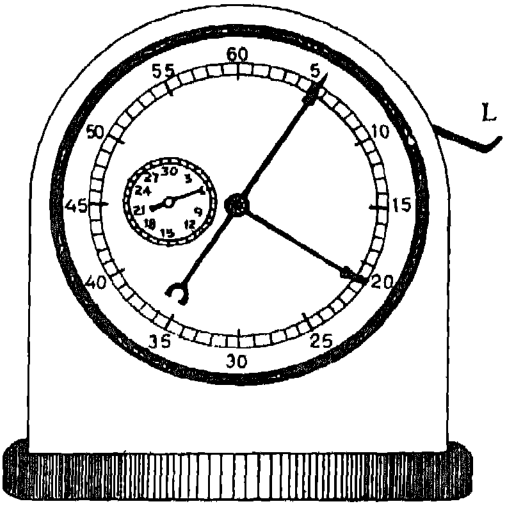


Fig. 2.18-a: *A stop-clock*

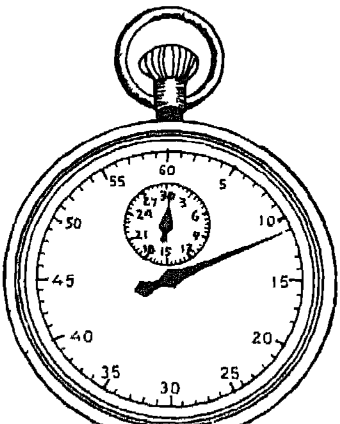


Fig. 2.18-b: *A stop-watch*

The basic principle behind all time-measuring devices is a series of events that repeat regularly. You would have seen the use of clapping by musicians to provide 'tal' (rhythm). This is the simplest form of uniform repetitive event which one can practise easily. You may have noticed that old wall clocks keep time by the swinging pendulum. A similar device can easily be set up to measure short intervals of time. It is called a *simple pendulum* (Fig. 2.19). A small spherical metal-bob is suspended from a long thread (about 1 m in length) with the help of a hook provided on the bob. You pull the bob a little to one side and release it. You will observe that the time taken by the pendulum to complete one swing always remains the same so long as you do not change its length. You can easily verify that the time taken to complete one oscillation (swing) increases with increase in the length of the pendulum. The time taken for one swing is called *time period* of the simple pendulum.

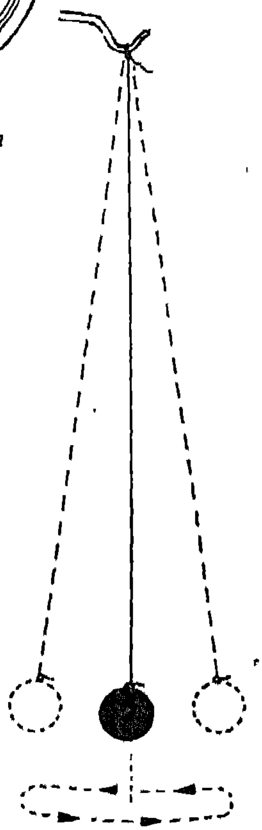


Fig. 2.19: *A simple pendulum. At the bottom is shown one complete swing.*

Time intervals for some events can be seen in Fig. 2.20 Different devices are used for measuring time intervals in different ranges.

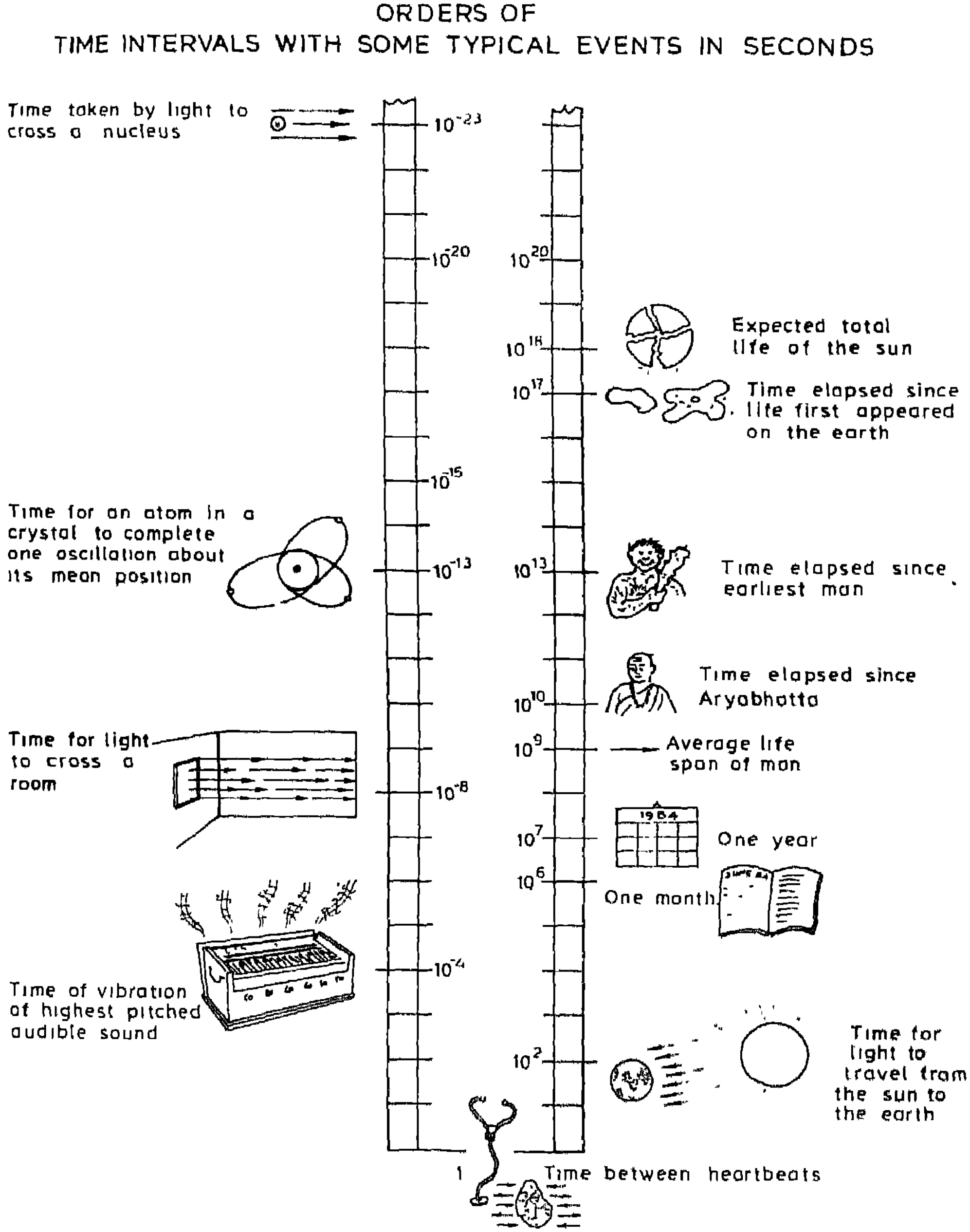


Fig. 2.20: *Orders of time intervals with some typical events in seconds.*

ACTIVITIES

1. Draw a square of 5 cm. With the aid of scale and compass draw a square with twice the area of this square. (**Hint:** Calculate the length of the diagonal of the square.)
2. Imagine a cube of side 5 cm. In relation to this cube, think of a length, using which as one side, if you construct a cube, it will have three times the volume. (**Hint:** Calculate the length of the main diagonal of the cube.)
3. Take a graph paper of 25 cm × 25 cm and paste it on a cardboard of uniform thickness by spreading glue uniformly on the reverse of graph sheet and let it dry. Trace your hand on it. Cut along the outline and remove this piece. Also cut a square of side 5 cm × 5 cm. Weigh the square and determine the mass of the cardboard per square cm. Now weigh the piece giving the outline of the hand. Knowing its mass, find its area. Find the area by counting centimetre squares. Compare the two values.
4. Set up a simple pendulum and study its time period for different lengths.
5. Count your pulse for one minute and find the average time between two consecutive pulse beats. Do some brisk running for 5 minutes and again find the average time between two pulse beats.
6. Sometimes a doctor counts the pulse rate of a patient to tell whether he is normal or is running temperature. Count the pulse rate per minute of a few friends and find the average pulse rate for a normal person.
7. Request a friend to stand in a relaxed position. Ask him to swing his arm in a natural way. Find the time period of the swing. Ask him to hold in his hand a bag containing some heavy books or any other weight (about 1 kg). Let him now swing the hand again. Find the time period of the swing again. Are they the same? Which is larger? You will need a watch showing seconds for this activity.

QUESTIONS AND PROBLEMS

1. Suppose you are given a thin wooden metre scale and a thin plastic scale. Both the scales have identical graduations in millimetres and centimetres. Which one of these would you prefer to use? Give reason for your answer.
2. Describe briefly a way to find the thickness of a sheet of paper out of a thick bundle, by using an ordinary 15 cm long plastic scale. What can you say about accuracy of the result?
3. 50 cm of a copper wire of uniform diameter, wound in close turns on a round pencil (Fig. 2.21), is found to yield 20 turns. Average length of the coiled wire is

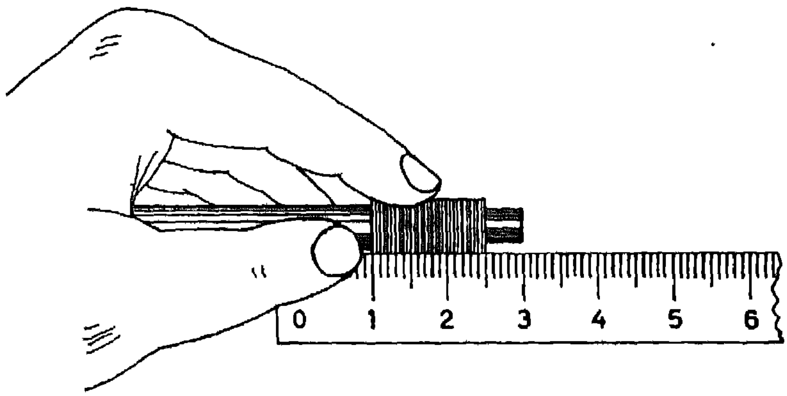


Fig. 2.21: *Wire, coiled round a pencil.*

1.5 cm Calculate the diameter of the wire and express it in metres and millimetres. Which device can be used to check the result?

[**Ans.** Diameter of the wire is 0.75 mm or 7.5×10^{-4} m]

4. How many squares, each of side 0.5 cm, will fill completely a square of side 2 cm? [**Ans.** 16 squares]
5. Calculate the surface area of a sphere of radius 10 cm correct to 0.1 cm^2. Given $\pi = 3.142$ [**Ans.** 1256.8 cm^2]
6. Calculate the area and perimeter of the following rectangles: (i) 10×6 cm^2 (ii) 12×4 cm^2, (iii) 14×2 cm^2, (iv) 8×8 cm^2. What do you infer from your results?

   Does the area depend upon shape of the rectangle? If so, how?

[**Ans.**	(i)	(ii)	(iii)	(iv)
Perimeter	32 cm	32 cm	32 cm	32 cm
Area	60 cm^2	48 cm^2	28 cm^2	64cm^2]

7. How will you find the volume of a small metallic key using a test-tube provided with a stand? You are also given a mm-graph sheet, cello-tape, 5 ml spoon and water (Fig. 2.22).

   [**Hint:** graduate the test-tube].

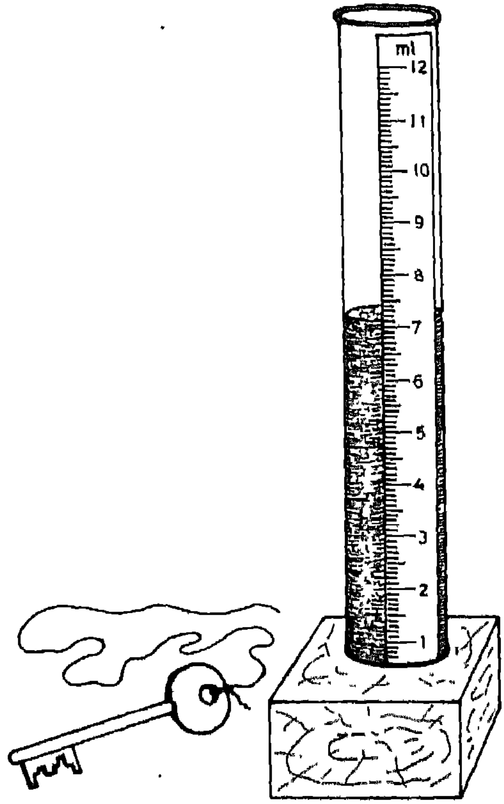


Fig. 2.22: *A possible view of the set-up for finding the volume of a key.*

8. How will you find the volume of a body that is soluble in water (but not soluble in other liquids)?
9. Consider 5 spheres of radii 1cm, 2cm, 4cm, 6cm and 10cm. Find the ratio of the surface area to volume in each case. Plot this ratio as a function of the radius. Does this ratio increase or decrease with the radius?

$$\left[\textbf{Hint: } \frac{V}{A} = \frac{4/3\pi r^3}{4\pi r^2} = \frac{r}{3}\right]$$

10. What is your height in metres and your weight in kilograms? Mention the date on which you observed these and the type of device you used to take these measurements How accurate are these values?
11. A body is weighed six times on a balance where the minimum weight is 1 g. The measurements are 102 g, 104 g, 98 g, 103 g, 101 g, 97 g. Find the average weight. (Give the answer after correctly rounding off the digits.)
[**Ans.** Average weight of the body is 101 g]
12. Density of water is 1×10^3 kg/m^3. What will be the density in g/cm^3.
[**Ans.** 1 g/cm^3]
13. What is meant by the terms density and relative density? What is the difference between the units of the two?
14. Find the number of seconds in (i) 1 day, (ii) 1 month (30 days) and (iii) 1 year (365 days).
15. The time of 20 oscillations of a pendulum is measured 4 times with the help of a stop-clock (least count 0.5 s). The results are: 26 s, 23.5 s, 25 s, 24 s. Find the average time of 20 oscillations and then determine the time period of oscillation.
[**Ans.** Average time for 20 oscillations: 24.6 s Time period of oscillation: 1.2 s.]
16. Round off the following values:

(i)	2 369 cm	least count: 0.01 cm
(ii)	8.235 g	least count: 1 g
(iii)	3125.67 m	least count: 1 m
(iv)	46.321 s	least count: 0.1 s
(v)	35.280 s	least count: 0.01 s

[**Ans.** (i) 2.37 cm; (ii) 8g; (iii) 3126 m (iv) 46.3 s and (v) 35.28 s]

CHAPTER 3

Displacement : Vectors

WE ARE ALL familiar with moving bodies. In everyday life we see many vehicles like bicycles, cars, buses and trains going from one place to another. We also move from one place to another while performing various activities. A common characteristic of all moving bodies is that they change their positions with time. For example, our position changes continuously when we go from one place to another. Hence, the first step in our study of motion should be to learn to state precisely the position of a body and also the changes in its position.

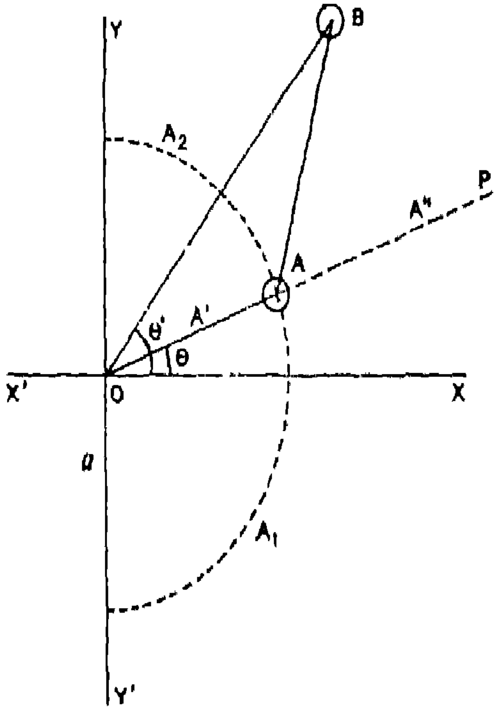


Fig. 3.1: *Displacements of a ball on the ground.*

3.1 Change of Position: Displacement

Suppose we want to describe the position of a body, say a ball, lying on the ground at some point A (Fig. 3.1). There are various ways of doing this. We consider one simple way. Take any point O on the ground and draw any line

OX passing through it. The position of the ball can be described precisely by measuring the distance OA and the angle θ, that the line OA makes with the line OX. We note that we need two measurements to describe the position of A. If we are given only one of the two quantities, then the position of the ball is not fully specified. If we know only the angle θ, then the ball may be at A or A′ or A″. As a matter of fact, it could be anywhere on the line OP which is an infinite extension of the line OA. On the other hand, if we know only the distance a between O and A, then the ball may be at A_1, A_2 or anywhere on the circle of radius a centred at O.

If the ball now moves from point A to another point B, its new position will be given by (i) the distance between the points O and B and (ii) the angle θ' between the lines OB and OX. We express all this by saying that the position of a point is defined by measuring its distance from a reference point (here O) and also the angle that the line joining the reference point to the given point makes with the reference axis (here OX). The change in position of the ball from point A to point B is called its *displacement*. This displacement is equal to the distance between points A and B measured along the direction AB. Thus the displacement of a body is described in terms of two quantities, a distance and a direction. The distance is called the *magnitude* of the displacement The displacement of a body will change if there is any change in either its magnitude or direction or both. Physical quantities which require a magnitude as well as direction to specify them are called *vector quantities* or *vectors*. Displacement is an example of a vector quantity. We will come across other vector quantities as we proceed.

On the other hand, there are other physical quantities which are completely specified by their magnitude alone. These are called *scalar quantities* or *scalars*. Distance, volume, mass, density, time, temperature are some examples of scalars.

In order to distinguish between scalars and vectors, vector quantities are printed in bold face or with an arrow over them. For example, the displacement between O and A will be printed as $\mathbf{a}$ or $\vec{OA}$ and written as $\vec{a}$ or $\vec{OA}$. The direction of the arrow indicates that the displacement is from O to A. The magnitude of a vector is printed in ordinary type, in the same manner as scalars. The magnitude of vector $\mathbf{a}$ will be printed (and written) as a*. In writing a vector quantity there must always be an arrow over it such as $\vec{a}$ or $\vec{OA}$ (for otherwise it will either mean a scalar or the magnitude of the vector). Most of the physical quantities we come across in nature are vectors. Vectors have many interesting properties and we will study some of these in the following sections.

3.2 Graphical Representation of Vectors

It is often convenient to represent a vector graphically, i.e., through a diagram. A straight line with an arrow-head is the most convenient method of representing a vector. The length of the straight line is drawn proportional to the magnitude of the vector, while the direction of the line, as indicated by the arrow-head, is in the direction of the vector. The end of the vector carrying the arrow-head is called the 'head' of the vector and the other end is called the 'tail' of the vector (Fig. 3.2).

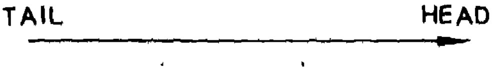
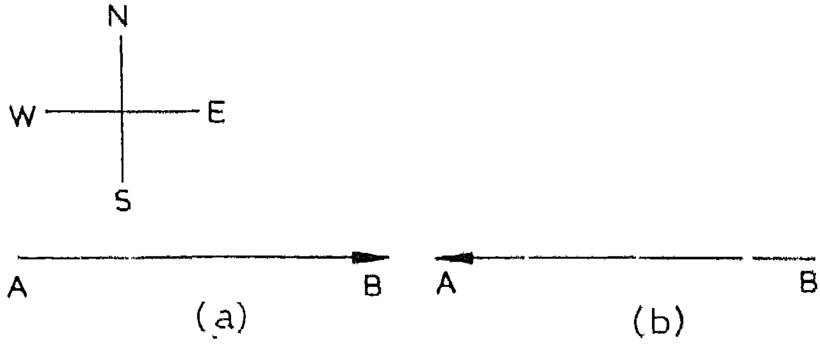


Fig. 3.2: *Graphical representation of a vector.*

* Also printed as $|\mathbf{a}|$ read as modulus vector a.

Suppose we want to represent a displacement of '100 km from west to east'. We will have to use a suitable scale to plot this displacement. Let us represent 20 km by 1 cm length of a line

Fig. 3.3-a,b: *Two displacement vectors in opposite directions.*



(Note that in drawing a vector any convenient scale may be taken.) Then the above displacement will be represented by a line of 5 cm length drawn from west to east, as shown in Fig. 3.3-a The direction of the arrow-head indicates that the displacement is from west to east. A displacement of the same magnitude in opposite direction will be represented by the vector shown in Fig. 3.3-b. Note that the displacements shown by Fig. 3.3-a and Fig. 3.3-b are not the same, though their magnitudes are equal. In general, two vectors of same magnitude but of opposite directions are related by the following relation:

$$\vec{AB} = -\vec{BA}$$

$$\text{or} \quad \vec{BA} = -\vec{AB}$$

Two vectors are said to be equal, if and only if, they have the same magnitude as well as the same direction. For example, from the point of view of vectors a displacement of '50 km north' at Bangalore is equal to a displacement of '50 km north' at Srinagar (Fig. 3.4). Here the scale used is 10 km ≡ 1cm. *Two equal vectors are represented by directed lines of equal lengths parallel to each other. Thus, an important property of vectors is that a vector can always be displaced parallel to itself without in anyway changing it.*

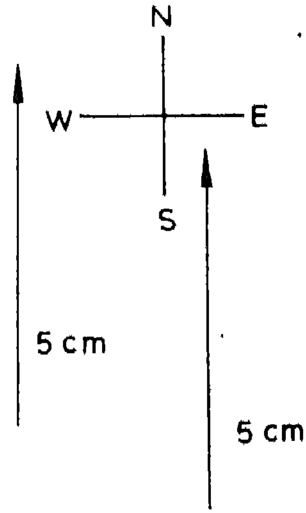


Fig. 3.4: *Two equal vectors.*

3.3 Addition of Vectors

Sometimes a body may undergo a number of successive displacements befo... final destination. The resultant displacement in such a case can be determined by a... successive displacements of the body. The rules for adding two or more vecto... kind, e g., displacements, are not the same as those for adding scalars. The sum of ... scalars can be obtained by simply adding them For example, addition of 2 litre... 4 litres of milk would give us 6 litres of milk. However, the addition of two or m... representing the same physical quantity cannot be done by simply adding the... because the direction associated with each vector has also to be taken into account. The ... two or more vectors also yields a vector called the *resultant vector* or simply the ...

If the vectors to be added are all in the same direction, the resultant vector has a magnitude equal to the sum of the magnitudes of all the vectors involved and its direction is the same as that of any of the vectors. For example, if a body is displaced 1 m along the eastern direction and further displaced by 0.5 m in the same direction, the total displacement of the body would be 1 5 m along the east (Fig 3.5-a, b).

Fig. 3.5: (a) *Two unequal parallel ve...*
(b) *Addition of two unequal parallel ve...*

If two vectors are directed in opposite directions, their resultant will have a magnitude equal to the difference in the magnitudes of the vectors involved. Further, the resultant will have the same direction as that of the vector having the greater magnitude. Suppose from the ground floor you go up by a lift to the fifth floor and then come down to the third floor. The displacement corresponding to the first change in position would be '5 units upwards', assuming all floors have the same height. The displacement while coming down would be '2 units downwards'. The resultant displacement would be (5−2) units, i.e., '3 units upwards' (Fig. 3.6).

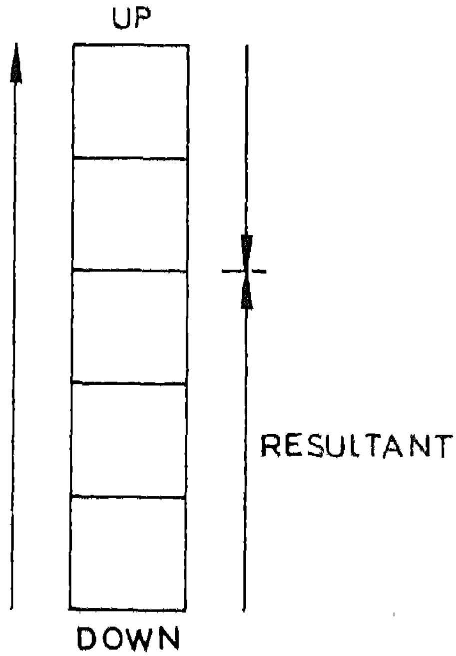


Fig. 3.6: *Addition of two vectors in opposite directions.*

If the vectors to be added have different directions, their resultant can be obtained by graphical method. The simplest procedure is to arrange the vectors by moving them parallel to themselves in such a way that the

tail of the second vector coincides with the head of the first vector, and the tail of the third vect coincides with the head of the second vector, and so on (Fig. 3.7). We can do this becaus

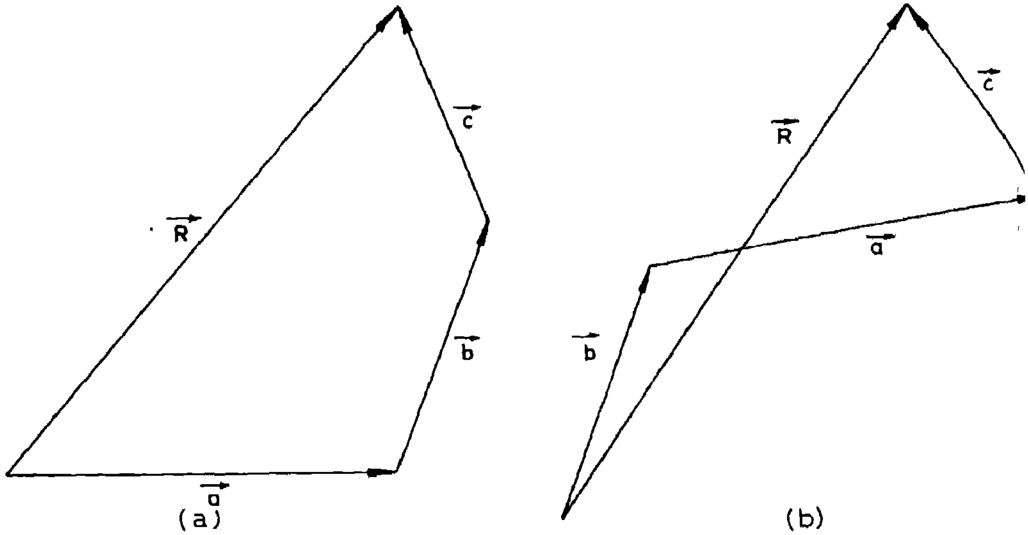


Fig. 3.7-a,b: *General rule for addition of vectors. The resultant is independent of the order i which the vectors are added.*

vector can always be displaced parallel to itself without in anyway changing it. The resultan vector $\vec{R}$. is obtained by joining the tail of the first vector to the head of the last vector. It is a important property of addition of vectors that the resultant is independent of the order in whic the vectors are added For example, in Fig. 3.7-b the same vectors as given in Fig. 3.7-a ar added in a different order and we find the same resultant $\vec{R}$:

$$\mathbf{a} + \mathbf{b} + \mathbf{c} = \mathbf{b} + \mathbf{a} + \mathbf{c} = \vec{R} \qquad (3.1)$$

Let us consider a special case of addition of two vectors at right angles to each other. The resultant can be obtained by graphical method described above. However, the magnitude of the resultant can also be determined without having to draw the figure.

Suppose **a** and **b** are two vectors at right angles to each other. The resultant will be given by vector **c** as shown in Fig. 3 8. Here **a** $= \vec{AB}$, $\mathbf{b} = \vec{BC}$ and $\mathbf{c} = \vec{AC}$. It can be seen that points A, B and C form a right-angled triangle

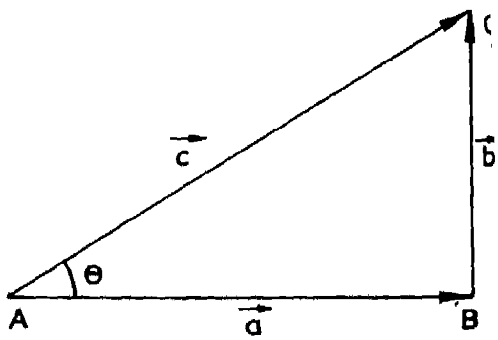


Fig. 3.8: *Addition of two vectors at right angles to each other by graphical method.*

and therefore using Pythagoras theorem we get

(length of side AC)^2 = (length of side AB)^2 + (length of side BC)^2.

Since the length of each side of the triangle is proportional to the magnitude of the corresponding vector, we can write

$$a^2 + b^2 = c^2 \qquad \text{or} \quad c = \sqrt{a^2 + b^2} \tag{3.2}$$

Since the magnitude of a vector is always taken as positive, in taking the square root we keep the positive sign only. The direction of the resultant will be known if we know the angle θ between vectors **a** and **c**. This angle can be determined either by direct measurement or in terms of trigonometric functions. We will learn about trigonometric functions in subsequent chapters. In general, if **a** and **b** are two vectors, and **c** is their resultant, we express this relationship by the equation

$$\mathbf{c} = \mathbf{a} + \mathbf{b} \tag{3.3}$$

Note that when the plus sign appears between two vectors, it implies addition according to the law of addition of vectors (Fig 3.9-a).

Suppose we want to subtract vector **b** from vector **a**. If **d** represents the difference of these vectors, then

$$\mathbf{d} = \mathbf{a} - \mathbf{b}$$

which can be written as

$$\mathbf{d} = \mathbf{a} + (-\mathbf{b}) \tag{3.4}$$

whereas in equation 3.4, vector $-$**b** has the same magnitude as vector **b** but is directed in opposite direction. Subtracting **b** from **a** is therefore equivalent to adding $-$ **b** to **a**.

We note that in adding **a** to $-$ **b** we displace $-$ **b** parallel to itself such that its tail coincides with the head of **a** (Fig. 3.9-b).

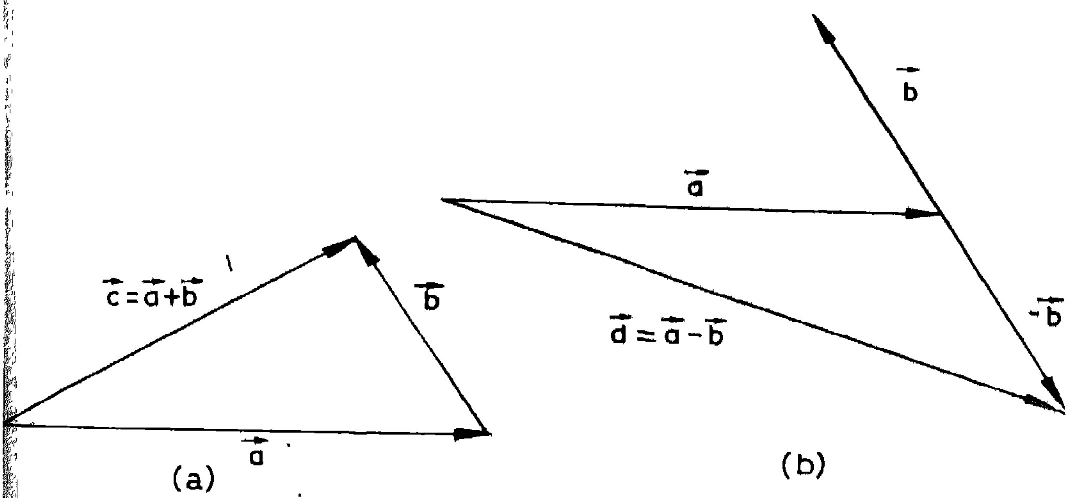


Fig. 3.9-a, b: ***Addition and subtraction of two general vectors.***

Example 1: A boy walks from his school to the post-office situated '1.2 km east' and then walks to his home situated '0.5 km north' of the post-office. Find the magnitude of his resultant displacement.

It is convenient to represent 0.2 km by 1 cm length of a line. Thus, we draw a line SP along the eastern direction, whose length is 6 cm, to represent the displacement of 1.2 km from the school to the post-office. Similarly, a perpendicular line PH of length 2.5 cm is drawn (Fig. 3.10) towards north to represent a displacement of 0.5 km from the post-office to the home. Then SH represents the resultant. Its measured length is 6.5 cm which means a displacement of 1.3 km. The measured value of angle HSP = 22.6°.

Alternatively, the magnitude of resultant can be calculated by using Pythagoras theorem as below.

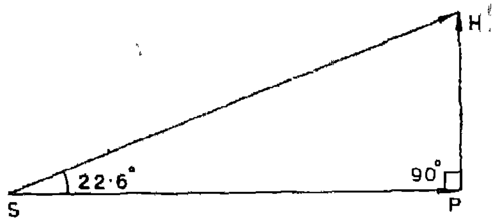


Fig. 3.10: *Addition of vectors*

$$\begin{aligned}(\text{magnitude of } \vec{SH})^2 &= (\text{magnitude of } \vec{SP})^2 + (\text{magnitude of } \vec{PH})^2\\ &= (1.2\ \text{km})^2 + (0.5\ \text{km})^2\\ &= 1.44\ \text{km}^2 + 0.25\ \text{km}^2\\ &= 1.69\ \text{km}^2\end{aligned}$$

$$\therefore \text{ magnitude of SH} = \sqrt{1.69\ \text{km}^2} = 1.3\ \text{km}.$$

There is an alternative way of adding two vectors whose tails coincide at one point. Suppose we want to add two vectors $\mathbf{a} = \vec{OA}$ and $\mathbf{b} = \vec{OB}$, (Fig. 3.11-a). To determine the resultant, we complete the parallelogram OACB. The main diagonal OC is the resultant vector **c**. We note that the tail of the resultant vector **c** is also at the point O. This method works

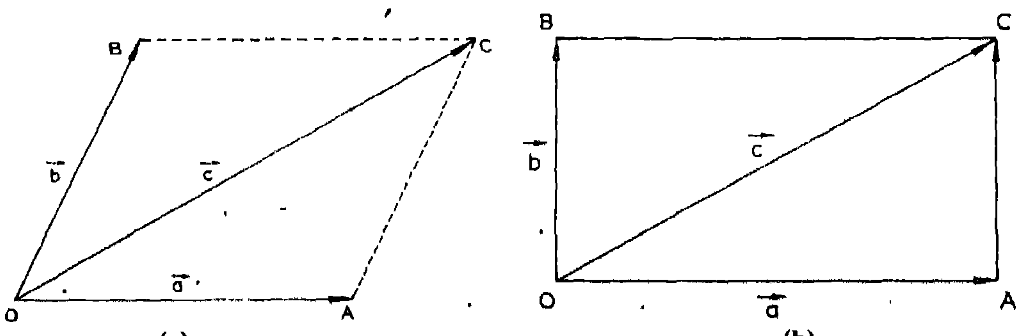


Fig. 3.11-a, b: *Addition of vectors using law of parallelogram. A rectangle is a special case of parallelogram.*

because as we mentioned earlier we can displace any vector parallel to itself and hence vector $\vec{AC}$ is equal to vector $\vec{OB}$, and we know that

$$\vec{OC} = \vec{OA} + \vec{AC} \tag{3.5}$$

We note that given any two vectors, their sum is uniquely determined. It does not depend upon the method of adding them. If two vectors are at right angles to each other, then obviously their resultant will be given by the concurrent diagonal of the rectangle formed by them (Fig. 3.11-b).

QUESTIONS AND PROBLEMS

1. Define scalar and vector quantities and give two examples of each. What is the difference between distance and displacement?
2. Consider two displacements, one of magnitude 3 metres and another of magnitude 4 metres. Show how these displacement vectors may be combined to get a resultant displacement of (a) 7 metres (b) 1 metre and (c) 5 metres.
3. Find the resultant vector in the following cases:
   Given **a** = 5 units along east, **b** = 6 units along north-west, **c** = 2 units along south.
   Find (i) **a** + **b** + **c**, (ii) **a** + **c** + **b**.
   (iii) **b** + **a** + **c**, (iv) **b**−**a**, (v) **c**−**b**
   [**Ans.** (i), (ii) and (iii) 2.4 units at 70° NE (iv) 10.2 units at 25° NW (v) 7.5 units at 56° SE.]
4. In the street map shown in (Fig 3.12), a man travels from A to B to C and then to D. Draw his resultant displacement.

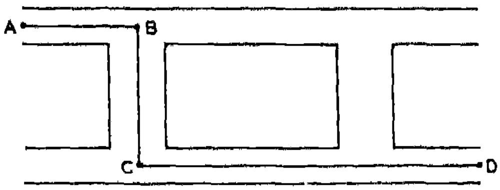


Fig. 3.12

5. Consider a displacement of 5 m towards east, and another of 6 m inclined at 30° towards north. Determine the sum and difference of these two displacement vectors.
   [**Ans.** Sum = 10.5 m along 17° NE
   Difference = 3 m along 2° WS]
6. Choosing appropriate scale, draw vectors corresponding to the following displacements:
   (i) 6 m, 60° north-east.
   (ii) 6 m, west.
   (iii) 25 m, 30° south-east

7. In Fig. 3.13 are shown three vectors $\vec{OA}$, $\vec{OB}$ and $\vec{OC}$. Find the resultant using the law of parallelogram.

8. Consider a displacement vector of 7 metres along east, another vector of 9 metres along north. Determine the resultant of these vectors graphically. Verify your answer for magnitude of the resultant using Pythagoras theorem.

[Ans: 11.4 m along 52° NE]

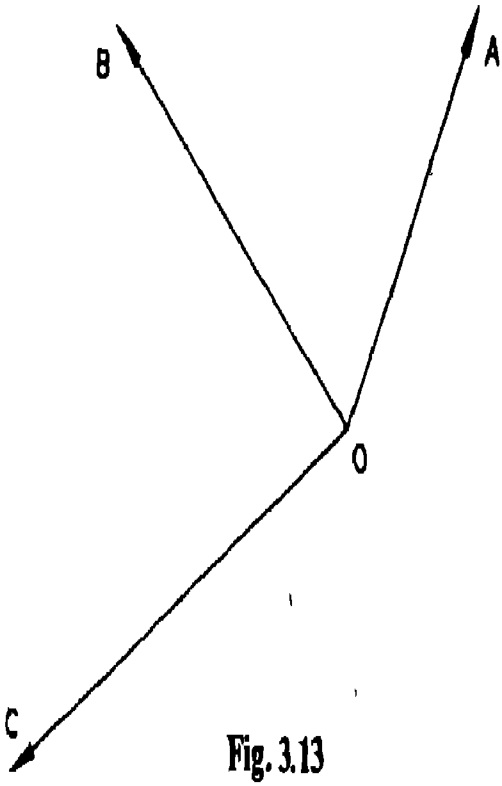


Fig. 3.13

CHAPTER 4

Motion: Uniform and Non-Uniform

4.1 Motion

LET US CONSIDER the motion of a body along a straight line, for example, a ball dropped from a height. If we could measure the distance travelled by the body in successive one second intervals, we would find that the ball travels larger distances in later time intervals, as shown in Fig 4.1. This is an example of *non-uniform motion*. In the special case when the body covers equal distances in equal intervals of time, we say that the motion is *uniform*.

Another possible arrangement for studying motion in a straight line is shown in Fig. 4.2. The trolley can be moved by adjusting the weights kept on the pan. The position of the moving trolley at different times is recorded by the drops of ink falling at regular intervals on a strip of paper placed on the table and on which the trolley moves. (The time-interval between two drops can be adjusted.) The distance between two successive drops is the distance covered by the trolley in the time-interval between two drops (This time-interval can be determined by counting the number of drops in, say, one minute while keeping the flow the same) The records of ink drops for three such runs of a trolley, with three

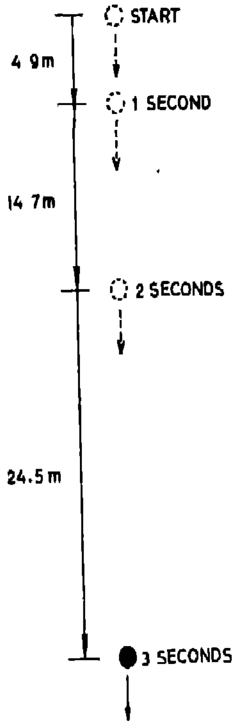


Fig. 4.1: *Distance covered by a freely falling body in successive seconds.*

different weights in the pan are shown in Fig. 4.3. We note that the distance between any two successive dots is the same in the first case, whereas it goes on increasing with time in the next two cases. Thus, the motion is uniform in the first case, and non-uniform in the next two cases. If we plot the distance travelled by the body in a given time-interval, t, for the case of uniform motion we will get a graph as shown in Fig. 4.4. On the other hand, for non-uniform motion (e.g. case (ii) or (iii) of Fig. 4.3) we get a graph as shown in Fig. 4.5. We note that for uniform motion, distance-time graph is a straight line.

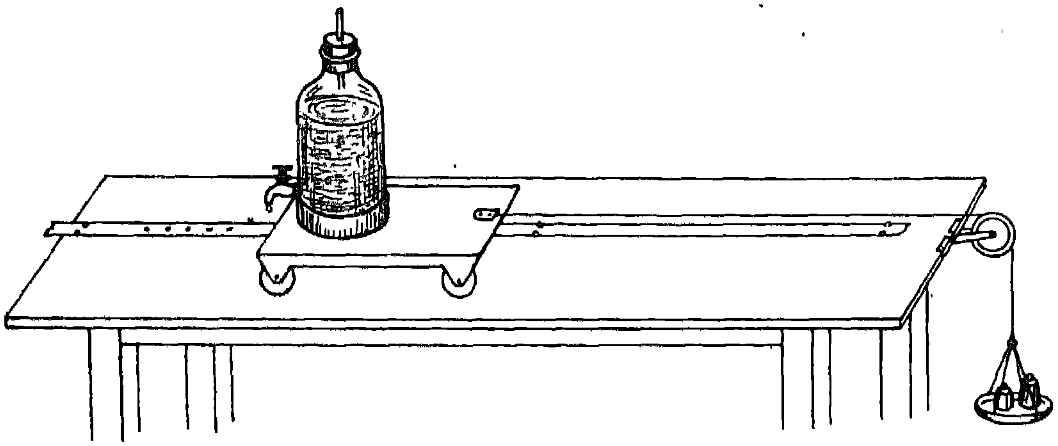


Fig. 4.2: *Set-up of the trolley experiment for uniform and non-uniform motion.*

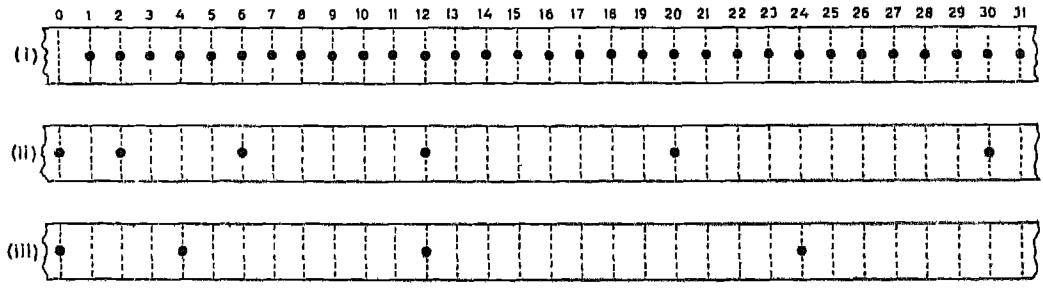


Fig. 4.3: *Strips (i) to (iii) showing three different motions of the trolley. Each dot is to be considered as a spot of ink. On each strip, time-interval between two consecutive dots is the same.*

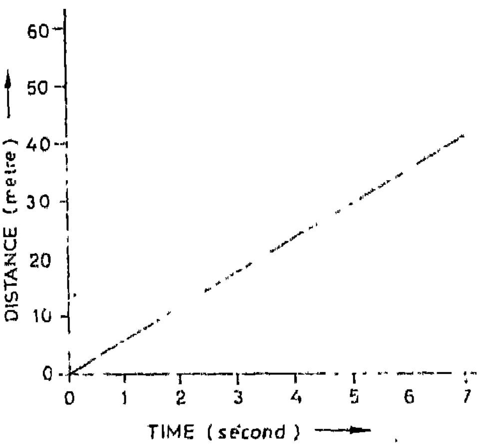


Fig. 4.4: *Plot of distance covered by a body having uniform rectilinear motion in different time-intervals.*

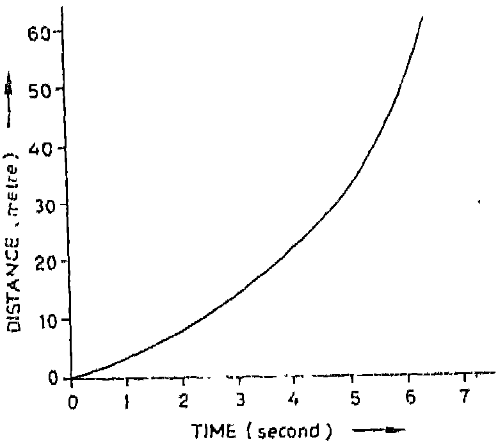


Fig. 4.5: *Plot of distance covered by a body in non-uniform rectilinear motion in different time-intervals.*

4.2 Speed

We have seen that the distance covered by a moving body depends upon the time for which we consider its motion Longer the time, larger is the distance covered by it. We define the *speed* of a body as the distance covered by it in a unit time interval. It is obtained by dividing the distance covered by the body, by the time it takes to do so. If a body moves by a distance, s, in time t, then its speed, v, is given by

$$\text{Speed} = \frac{\text{total distance moved by a body}}{\text{time taken}}$$

or $$v = \frac{s}{t} \qquad (4.1)$$

Consider the distance-time graph shown in Fig. 4.6. Take two points A and B with coordinates (x_1, t_1) and (x_2, t_2) respectively. Draw the triangle ABC as shown. Then the slope of the line between points A and B is

$$\frac{BC}{AC} = \frac{x_2 - x_1}{t_2 - t_1}$$

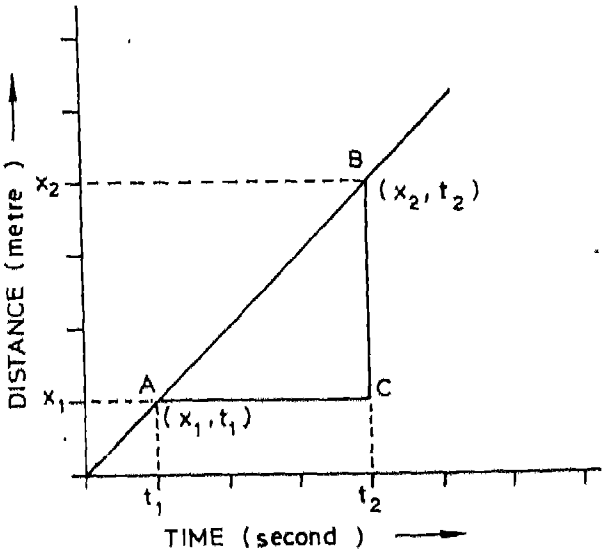


Fig. 4.6: *Slope of distance-time graph gives the speed of the body.*

Since the distance $x_2 - x_1$ is covered in the time-interval $t_2 - t_1$, the slope gives the speed of the body.

If the distance is measured in metres and time in seconds, the unit of speed will be metre/second, which we read as metre per second. This is a derived unit. It is often written as m/s or ms^{-1} where m and s stand for metre and second respectively. For the sake of convenience, other units of speed are also used. Centimetre per second (cm/s) and kilometre per hour (km/h) are two such common units.

Example 1: The distance between the house and the school of a boy is 1 8 km. If he takes 6 minutes to reach his school by bicycle, calculate his speed in metres per second. Express this speed in cm/s and km/h.

Distance covered, $d = 1.8$ km = 1800 m.
Time taken, $t = 6$ minutes = 360 seconds.

$$\text{Speed, } v = \frac{\text{distance}}{\text{time}} = \frac{1800\text{ m}}{360\text{ s}} = 5\text{m/s}.$$

Let us substitute the value of d in centimetres and t in seconds. Then, we get

$$v = \frac{180000\text{ cm}}{360\text{ s}} = 500\text{ cm/s}.$$

Similarly, by substituting value of d in kilometres and of t in hours, we get

$$v = \frac{1.8\text{ km}}{0.1\text{ h}} = 18\text{ km/h}$$

These results give the same speed in three different units. Hence they must all be equal, i.e.

$$5\text{ m/s} = 500\text{ cm/s} = 18.0\text{ km/h}$$

or

$$1\text{ m/s} = 100\text{ cm/s} = 3.6\text{ km/h}$$

This gives the relation between the three different units of speed.

4.3 Velocity

Knowledge of the speed of a body alone does not tell us where the body will be after some time. For example, consider a runner practising on a track. He runs very fast, but at the end of a few minutes he may be back on the same spot from where he started. Thus, though he ran very fast, at the end, his displacement is zero.

Thus there arises the need for specifying the direction of motion of a body along with its speed. When the speed of a body is given and also its direction of motion, it is called *velocity*. In other words, the *velocity* of a body is its speed in a given direction. It is a vector quantity. The magnitude of the velocity is speed. Thus, velocity has a definite magnitude and a definite direction. Any change either in the magnitude or the direction or both will change the velocity of the body.

The velocity of a body may be defined as displacement per unit time. If a body undergoes a displacement **s**, in a time-interval, t, then its velocity **v** is given by

$$\mathbf{v} = \mathbf{s}/t \tag{4.2}$$

The units of velocity are the same as those of speed. We note that relation (4.2) will hold provided the rate of change of displacement during the time interval, t, is uniform. In practice, however, the velocity of a body is seldom uniform over large periods of time For example, the speed as well as the direction of a train may undergo changes during its journey between two stations.

The velocity of a body at a given instant of time is known as its *instantaneous velocity*. It includes two pieces of information, the speed at that instant of time and the direction of motion at that same instant of time. The speed at any instant of time of many vehicles like cars, scooters, railway engines, etc., can be noted from the speedometer attached to the vehicle.

4.4 Average Speed

If the speed of a body changes continuously, we can still define a quantity, called the *average speed*. It is defined as the total distance covered, divided by the total time taken to cover this distance.

We consider the motion of a body along a straight line in a single direction (oscillatory motion is excluded) The distance-time graph of such a body (Fig. 4.7) can be used to find its average speed. Take four points A, B, C and D with coordinates (x_1, t_1), (x_2, t_2), (x_3, t_3) and (x_4, t_4) respectively. The average speed in the time-interval t_2-t_1 is

$$\frac{x_2-x_1}{t_2-t_1}$$

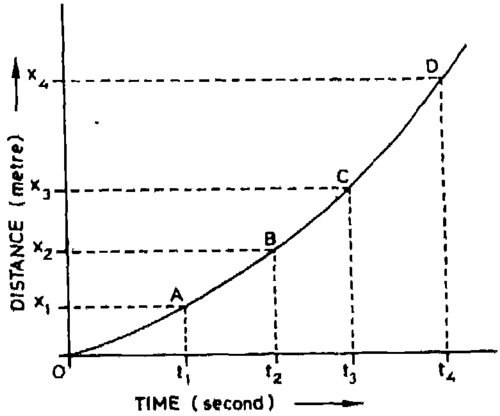


Fig. 4.7: *For non-uniform motion, average speed during different time-intervals is different.*

Similarly, the average speed in the time-interval t_4-t_3 is

$$\frac{x_4-x_3}{t_4-t_3}$$

Since we have chosen the time-interval (t_4-t_3) to be equal to the time-interval (t_2-t_1), it is obvious that the average speed in the interval (t_4-t_3) is higher than that in the interval (t_2-t_1).

If we want to calculate the average speed in the time interval (t_4-t_1) we will have to divide the distance (x_4-x_1) by (t_4-t_1). You will note that this average speed will be different from the average speed in the time intervals (t_4-t_3) or (t_2-t_1). If the motion is uniform (Fig. 4.4 or Fig. 4.6), the average speed in all time-intervals will be the same.

4.5 The Resultant Velocity

Sometimes the observed motion of a body may be due to superposition of two or more different motions. For example, when a bird flies against the wind, its speed is reduced. On the other hand, when it flies with the wind its speed increases. Let us consider a general case. Let the velocity of the bird when no wind is blowing be $\mathbf{v}_1$. Suppose the wind now begins to blow with a

velocity v_1, then the resultant velocity v_r of the bird will be given by the vector addition of these two velocities.

$$\mathbf{v}_r = \mathbf{v}_1 + \mathbf{v}_2. \tag{4.3}$$

$\mathbf{v}_r$ is called the *resultant velocity*. It can be determined by using the law of addition of two vectors discussed in Chapter 3

Example 2: A man is rowing a boat with a velocity of 5 km/h in a river, flowing with a velocity of 2 km/h. What would be the magnitude and direction of the resultant velocity of the boat with respect to the bank of the river, if the man rows

(a) in the direction of the flow,

(b) opposite to the direction of the flow, and

(c) perpendicular to the direction of the flow?

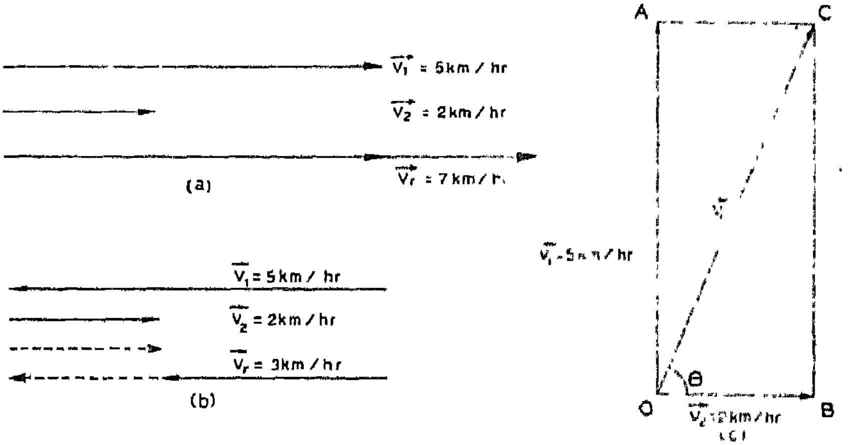


Fig. 4.8-a, b, c

(a) The magnitude of the resultant velocity will be 7 km/h and its direction will be the same as that of the flow of the river (Fig. 4.8-a).

(b) The magnitude of the resultant velocity would be 3 km/h in the direction opposite to that of the flow of the river (Fig. 4.8-b).

(c) In this case, the direction of motion of the boat and the river are at right angles to each other (Fig. 4.8-c). The magnitude of the resultant will be equal to the length of the vector $\vec{OC}$ and its direction will be along the diagonal OC of the rectangle. We can determine from Fig. 4.8-c, which has been drawn to scale (1 cm = 1 km/h), that $v_r = \vec{OC} = 5.4$ km/h and $\theta = 68°$.

The magnitude of the resultant can also be checked using Pythagoras theorem in the

following manner. From Fig. 4.8-c, it can be seen that

$$(\text{magnitude of } \vec{OC})^2 = (\text{magnitude of } \vec{OA})^2 + (\text{magnitude of } \vec{OB})^2$$
$$= 5^2 km^2/h^2 + 2^2 km^2/h^2 = 25 km^2/h^2 + 4 km^2/h^2 = 29 km^2/h^2$$

Hence the magnitude of v_r is $\sqrt{29}$ km/h = 5.385 km/h ≈ 5.4 km/h

It would be clear from example 2 (c) that although the boatman keeps his boat at 90° to the bank and is moving in this direction relative to the things floating on the water surface, his actual motion relative to the bank is different. He is carried downstream by water and the resulting motion is at 68° to the bank.

4.6 Acceleration

We know that in general the velocity of a body can change with time We consider here only the simple case in which velocity of the body changes at a uniform rate, i e., the amount of increase or decrease in the velocity in equal intervals of time is always the same. Such a motion is called *uniformly accelerated motion.* One example of uniformly accelerated motion is the motion of a bicycle going down an inclined road when the rider is not pedaling and wind resistance is negligible. In the laboratory, if a steel ball is allowed to roll down on an inclined plate of glass, its motion will also be nearly a uniformly accelerated one.

When a car or passenger bus starts moving, you can see on its speedometer that the speed is gradually increasing. If increase of speed in equal intervals of time is equal, it will be a case of uniformly accelerated motion.

The graph between velocity and time for uniformly accelerated motion is a straight line (Fig. 4.9). On the other hand, the change in velocity in successive equal intervals of time may not be the same and then the body is said to be in *non-uniformly accelerated motion.* The velocity-time graph for such a motion may have any shape (other than a straight line) as shown in Fig. 4.10.

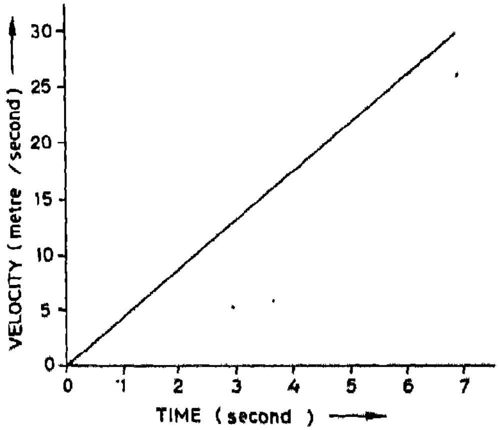


Fig. 4.9: *Velocity-time graph for a uniformly accelerated motion.*

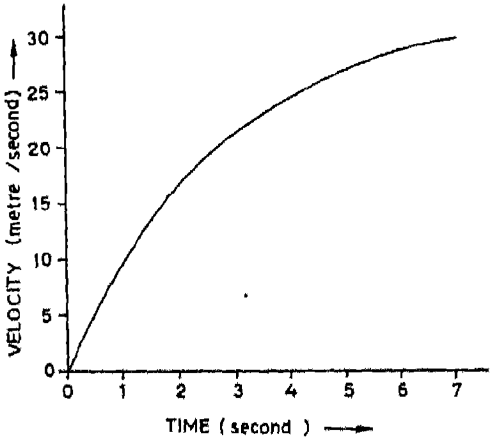


Fig. 4.10: *Velocity-time graph for a non-uniformly accelerated motion.*

We shall discuss only uniformly accelerated motions.

The rate of change of velocity of a body is defined as its *acceleration*. If the velocity of a body changes from **u** to **v** in a time interval, t, then its acceleration **a** is given by

$$\mathbf{a} = \frac{\text{change in velocity}}{\text{time}}$$

or
$$\mathbf{a} = \frac{\mathbf{v}-\mathbf{u}}{t} \tag{4.4}$$

The unit of acceleration is $\frac{\text{unit of velocity}}{\text{unit of time}}$. If velocity is expressed in $\frac{\text{m}}{\text{s}}$, then acceleration has the units $\frac{\text{m}}{\text{s}}$. $\frac{1}{\text{s}}$ or $\frac{\text{m}}{\text{s}^2}$. It is read as metre per second square. This unit can also be written as ms^{-2}.

Acceleration is a vector quantity. If the velocity of a body increases without change in direction, acceleration will have the same direction as the direction of the velocity and is taken as positive. If the velocity of a body decreases without change in direction, accleration is directed in the direction opposite to that of the velocity and is taken as negative. Such a negative acceleration is called *deceleration*.

4.7 Equations of Motion

There exist some relations between displacement, velocity, acceleration and the time-interval during which we study the motion of a body. These relations are called *equations of motion* of the body. For simplicity, here we will consider only motions along a straight line and a uniform acceleration will be assumed to act in the same direction as the velocity. Since here our direction of motion is fixed, we may talk only of magnitudes. Motion along a straight line is also called *rectilinear motion*.

Let us consider a body moving with an initial velocity, u, under a uniform acceleration, a. (Note that we are only considering the magnitudes of the vectors, because direction of motion is fixed.) Suppose it undergoes a displacement, s, in a time interval, t. At the end of this time interval, let its velocity be v.

Since acceleration is uniform, hence by definition, we have

$$a = \frac{v-u}{t} \quad \text{or, } a\,t = v - u, \tag{4.5}$$

which on rearranging the terms, can also be written as

$$v = u + a\,t. \tag{4.6}$$

Equation (4.6) gives a relation between the initial velocity, u, the final velocity, v, the time interval, t, and the acceleration, a. It tells us that if a body with starting velocity, u, is accelerated for time, t, by an acceleration, a, then its final velocity v, will be given by this equation.

The displacement of the body, s, in time, t, can be obtained by considering the average velocity, v_{av}, of the body. Since initial and final velocities of the body are u and v respectively, its average velocity, v_{av}, will be given by*

$$v_{av} = \frac{u+v}{2} \tag{4.7}$$

The displacement, s, of the body in time, t, which is moving with an average velocity v_{av} will be

$$s = v_{av}\, t = \frac{(u+v)\, t}{2} \tag{4.8}$$

Substituting the value of v from equation (4.6), we get,

$$s = \frac{[u + (u + at)]t}{2}$$

or

$$s = ut + \tfrac{1}{2} at^2. \tag{4.9}$$

This is a very important result and helps us to calculate the distance travelled by a body under uniform acceleration in a given time.

An expression for the displacement in terms of the initial and final velocities can also be obtained by elimination of t from equations (4.6) and (4.8). From equation (4.6), we have

$$t = \frac{v-u}{a}$$

Substituting this value of t in equation (4.8), we get

$$s = \frac{(u+v)}{2} \cdot \frac{(v-u)}{a}$$

or

$$2\, as = v^2 - u^2. \tag{4.10}$$

Equations (4.6), (4.9) and (4.10) are the equations of motion and any one of them completely describes the motion of a body under uniform acceleration. These are useful in solving various kinds of problems regarding uniformly accelerated motion.

Example 3: A bicycle moving with a velocity of 3 m/s speeds up with an acceleration of 0.5 m/s². What will be its velocity after 5 seconds and how far will it have moved during this time?

We are given

$$u = 3 \text{ m/s},\ a = 0.5 \text{ m/s}^2,\ t = 5 \text{ s}$$

*This holds exactly for uniformly accelerated rectilinear motions only.

From equation (4.6)

$$v = u + at$$
$$= 3\ \text{m/s} + 0.5\ \text{m/s}^2 \times 5\ \text{s} = 3\ \text{m/s} + 2.5\ \text{m/s} = 5.5\ \text{m/s}.$$

Hence the velocity of the bicycle at the end of 5 seconds will be 5.5. m/s.
From equation (4.9), we have

$$s = ut + \tfrac{1}{2} at^2$$

or $$s = 3\ \text{m/s} \times 5\text{s} + \tfrac{1}{2}\,(0.5)\ \text{m/s}^2 \times (5)^2\ \text{s}^2$$
$$= 15\ \text{m} + \tfrac{1}{2}\, 0.5 \times 25\ \text{m} = 15\ \text{m} + 6.25\ \text{m} = 21.25\ \text{m}.$$

Example 4: A ball is thrown vertically upwards. It reaches its maximum height in 2.5 seconds. If the acceleration of the ball be 10 m/s^2 directed towards the ground, find the initial velocity of the ball.

When the ball is thrown upwards its velocity will go on decreasing, because the acceleration is directed opposite to the direction of its motion. As a result, ultimately the velocity of the ball will become zero. This will correspond to the maximum height to which the ball will rise. We are given

$$v = 0\ \text{m/s};\ t = 2.5\text{s, and } a = -10\ \text{m/s}^2$$

The minus sign indicates that acceleration is in a direction opposite to the direction of motion of the ball. Substituting the values of v, a and t in equation (4.6), we obtain

$$0 = u - 10\ \text{m/s}^2 \times 2.5.\ \text{s}$$

or $$u = 25\ \text{m/s}.$$

Thus the initial velocity of the ball is 25 m/s.

4.8 Circular Motion

We have discussed above motion along a straight line. The path of a moving body need not necessarily be a straight line. For example, the path of a vehicle moving along a curved road is not along a straight line.

An athlete, before throwing the hammer, whirls it in a circle (Fig 4.11). We will now consider another simple form of motion, i.e., motion of a body in a circle.

Tie a piece of stone on one end of a thread and by holding the other end, make it go round in a circle (Fig. 4.12). If you let the string go, the stone will not move in the circle any longer. It will immediately fly off tangentially (Fig. 4.13). If the stone is released when it is at A, it will fly off along the tangent to the circle at this point, shown by the dotted line. Similarly, if the stone is at B when released, it will fly off along the tangent at B. It will be seen that the direction of motion is not the same at any two points. Even if we consider two points very close to each other, say, at P and Q (Fig. 4.14), even then the directions followed by the stone on release will be different. Thus, one of the characteristic features of circular motion is that the direction of motion of a body changes continuously with time. We know that a change in the direction of

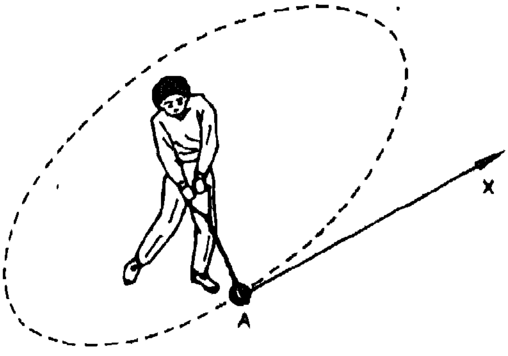


Fig. 4.11: *An athlete throwing hammer. If the hammer is released when it is at A, it will fly off along the tangent AX.*

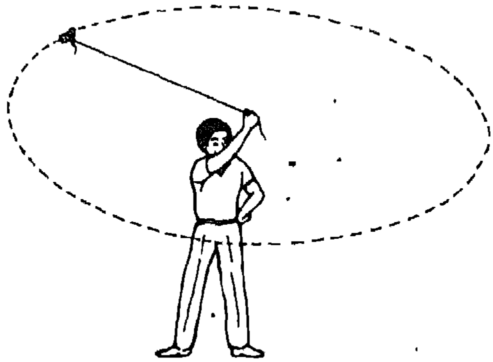


Fig. 4.12: *Circular motion of a stone tied to a string.*

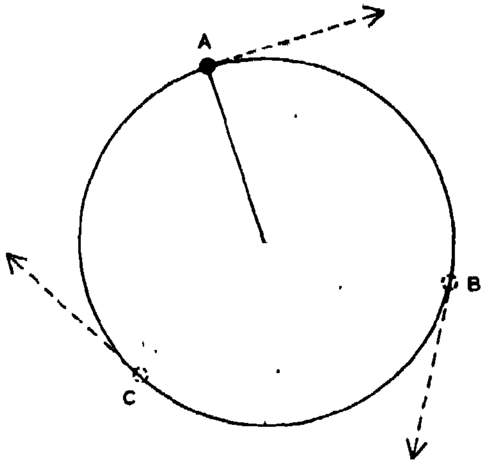


Fig. 4.13: *A body moving in a circle ABC. Arrows show the direction in which the body will fly off if released at A, B or C.*

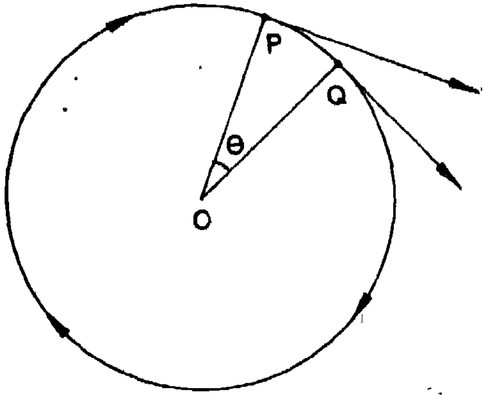


Fig. 4.14: *Circular motion of a body. Direction of motion changes even during a short time-interval.*

motion implies a change in velocity. Thus, *circular motion is an accelerated motion, even though the speed of the body remains constant.*

To find the speed of a body in circular motion, let us suppose that it moves through an arc PQ of length, s, in time, t (Fig. 4.14). Then its speed, v, will be

$$v = \frac{s}{t}$$

or

$$s = v \cdot t. \tag{4.11}$$

If the angle subtended by the arc PQ at the centre of the circle is θ radians, then by the definition of the angle, we have

$$\theta = s/r,$$

or
$$s = r\,\theta \qquad (4.12)$$

where r is the radius of the circular path. We note that here θ is in radians. Eliminating s from equations (4.11) and (4.12), we have

$$vt = r\,\theta$$

or
$$\frac{\theta}{t} = \frac{v}{r}$$

The ratio θ/t is the rate of change of angle and is called the *angular speed*. It is represented by ω (Greek letter omega). We therefore have

$$\omega = \frac{\theta}{t} = \frac{v}{r}$$

or,
$$v = \omega r \qquad (4.13)$$

Angular velocity has the units of radians per second or rad/s.

Example 5: Find the angular speed of the minutes hand of a wall clock, assuming that it moves with a uniform angular speed. Let the length of the minutes hand be 14 cm. Find the speed (v) with which the tip of the minutes hand moves.

We know that the minutes hand makes one complete round in one hour, i.e., in 3600 seconds. Thus

$$t = 3600 \text{ s, and } \theta = 2\pi \text{ rad}$$

$$\therefore \omega = \frac{\theta}{t} = \frac{2\pi}{3600} \text{ rad/s}$$
$$\approx 0.00174 \text{ rad/s} = 1.74 \times 10^{-3} \text{ rad s}^{-1}$$

The speed of the tip of the minutes hand is given by

$$v = \omega\, r$$
$$= \frac{2\pi}{3600} \times 14 \text{ cm/s}$$
$$\approx 0.0244 \text{ cm/s} = 2.44 \times 10^{-2} \text{cm s}^{-1}$$

Note: It is noteworthy that in most mechanical clocks the motion of the minutes hand is non-uniform. It moves in steps of one minute, i.e. in steps of $2\pi/60 = 1.05 \times 10^{-1}$ rad/min. For such a clock, the above result gives the average angular speed of the minutes hand.

Example 6: A scooter is racing at a speed of 72 km/h. Find the angular speed of the wheels, if radius of each wheel is 20 cm.

Here we have

$$v = 72 \text{ km/h} = 20 \text{ m/s}$$
$$r = 20 \text{ cm} = 0.2 \text{ m}$$

Hence

$$\omega = \frac{v}{r} = \frac{20}{0.2} \text{ rad/s}$$
$$= 100 \text{ rad/s}$$

ACTIVITIES

1. In a room in which air is almost still, make marks on a wall at 50 cm, 100 cm and 150 cm from the ground and label them as such (Fig. 4.15). Drop a very small piece of tissue paper (say a 3 or 4 mm corner of a paper) in turn from each mark. Estimate the time of fall in each case by fast counting. Interpret the result to decide what kind of motion it has during the fall (uniform motion/uniformly accelerated/changing acceleration and what kind of path it makes).
2. In a room in which air is still make a vertical scale on a wall from 0 to 150 cm, starting from the ground. The floor should be pucca, preferably cemented (or place a tile on the floor). Drop a ping-pong ball from a height of 30 cm. Note the height up to which it rebounds. This height of rebound depends on the velocity with which it strikes the ground. In successive trials increase the starting height to 50 cm, 80 cm, etc., and note the height of rebound in each case. Plot a graph between the starting height and height of rebound. After what starting height the velocity of hitting the ground is approximately constant? If a ping-pong ball falls from a great height, then

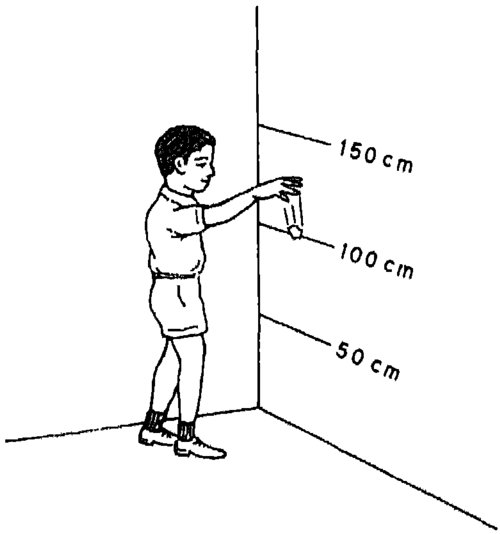


Fig. 4.15: *A small piece of paper being observed against the scale on the wall, as it falls towards the ground.*

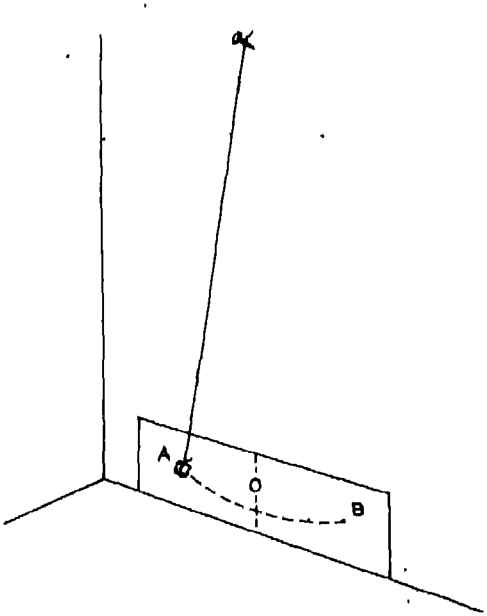


Fig. 4.16: *Simple pendulum improvised with a stone.*

(i) for what distance is motion accelerated?
(ii) if the acceleration changes during this distance, how does it change?
(iii) what is the nature of motion after this distance?

3. (a) Make a simple pendulum as described in the section on practical work. At home, you can improvise it by tying a stone or any heavy object by a thin thread about a metre long. Hang it by a nail in the wall. Oscillate it in a plane parallel to the wall. Observe and describe how the velocity of the bob changes as it moves from one end of motion to the other, e.g., from A to B (Fig. 4.16).

(b) Imagine two frictionless planes, equally inclined to the horizontal and facing each other (Fig. 4.17). A steel ball rolls down one plane, then ascends the other to the same height and then comes back. Thus it keeps on oscillating. Try to list similarities and differences between this motion and that of the pendulum.

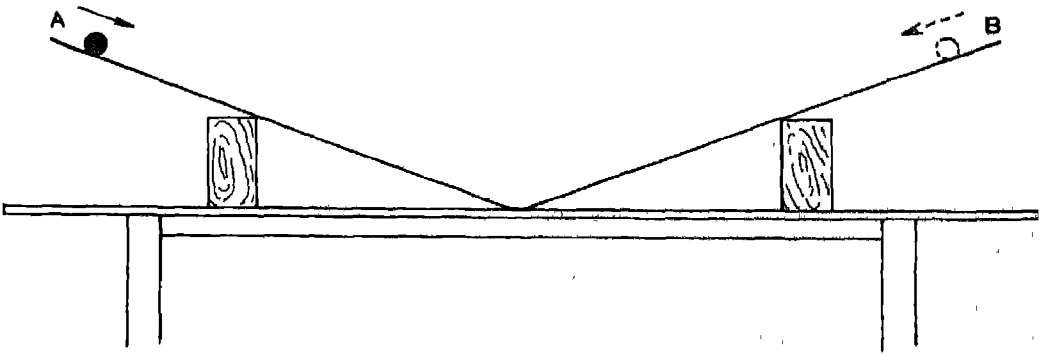


Fig. 4.17: *A pair of equally inclined, frictionless planes.*

4. Collect as much data as you can about the normal speeds at which various creatures move (e.g. snail: 10 cm/min, walk of man: 1.5 m/s, cheetah, the fastest land animal: 100 km/h, and so on) Arrange them in increasing order.

QUESTIONS AND PROBLEMS

1. The positions of a ball, rolling down an inclined plane, at the end of each second are given in the following table.

Time in second	0	1	2	3	4	5
Position in centimetre	0	10	40	90	160	250

Plot a displacement-time graph for the motion of the ball. Indicate whether the motion is uniform or non-uniform.

2. Give five examples of bodies in non-uniform motion.
3. Plot speed-time graph of bodies moving with uniform speeds of 4 m/s and 7 m/s. Compare the graphs.
4. Plot distance-time graph of bodies moving with uniform speeds of 4 m/s and 7 m/s. Compare the graphs.
5. A car attains a speed of 10 m/s in 10 s, starting from rest. Calculate the acceleration of the car.

[**Ans.** 1 m s^{-2}]

6. A wooden slab, starting from rest, slides down an inclined plane of length 10 m with an accleration of 5m/s^2. What would be its speed at the bottom of the inclined plane?

[**Ans.** 10 m/s]

7. What is the difference between uniform linear motion and uniform circular motion?
8. Calculate the angular speed of the seconds hand of a clock, assuming that it moves with a uniform angular speed. If the length of the seconds hand is 2 cm, calculate the speed of the tip of the seconds hand.

[**Ans.** $\frac{\pi}{30}$ rad/s, $\frac{\pi}{15}$ cm/s]

9. An artificial satellite takes 90 minutes to complete its revolution around the earth. Calculate the angular speed of the satellite.

[**Ans.** $\frac{\pi}{2700}$ rad/s]

10. A body is released from a height of 20 m. If a = 10m/s^2, calculate the velocity of the body when it hits the ground. Also calculate the time it takes to fall through this height.

[**Ans.** 20 m/s, 2s]

11. A train starting from rest and moving with a uniform acceleration attains a speed **of 90 km per hour** in 5 minutes. Find (a) the acceleration and (b) the distance **traversed.**

[Ans. (a) $\frac{1}{12}$ m/s^2 ; (b) 3.75 km]

12. A bus starting from rest moves with a uniform acceleration of 0.1 m/s^2 for 2 **minutes. Find** (a) the speed acquired and (b) the distance travelled.

[Ans. (a) 12 m/s; (b) 720 m]

13. A train is travelling at a speed of 90 km per hour. The brakes are applied so as to **produce a uniform** acceleration of -0.5 m/s^2. Find how far the train goes before it **stops.**

[Ans. 625 m]

14. A car travelling at 45 km/h is brought to rest with uniform retardation in 30 **seconds. Calculate** the retardation of the car.

[Ans. 0.417 m/s^2]

15. Find the initial velocity of a train which is stopped in 20 seconds by applying **brakes.** The retardation due to brakes is 1.5 m/s^2.

[Ans. 30 m/s]

16. A person rows his boat in a stream with a speed of 2.0 m/s. Water in the stream is **flowing with a** speed of 1.5 m/s To cross the stream, if he rows perpendicular to **the direction** of flow, find graphically his resultant velocity.

[Ans. 2.5 m/s]

17. If the stream in Problem No. 16 is 150 metres broad, how much time does he take **to cross it?** Also find how far downstream he reaches on the other bank.

[Ans. 75 s, 112.5 m]

18. In Problem No. 16, if the person wants to reach the other bank directly opposite **the starting point**, how should he row?

19. In Fig. 4.3, suppose the distance between two successive vertical dotted lines is **1 cm. Let the time** interval between two successive drops be 0.1 seconds. Find the **speed of the trolley** for strip 1. Find the acceleration of the trolley for strips 2 and 3.

20. Calculate the angular speed of the earth as it spins around its axis. Find the speed, v, **with which** a person standing on the equator is carried round. (Radius of the **earth** $\approx$ **6400** km.)

(Ans. $\frac{\pi}{43200}$ rads/s, $\frac{4\pi}{27}$ km/s]

21. What type of motion is represented by each of the following graphs? Comment on each in a few words.

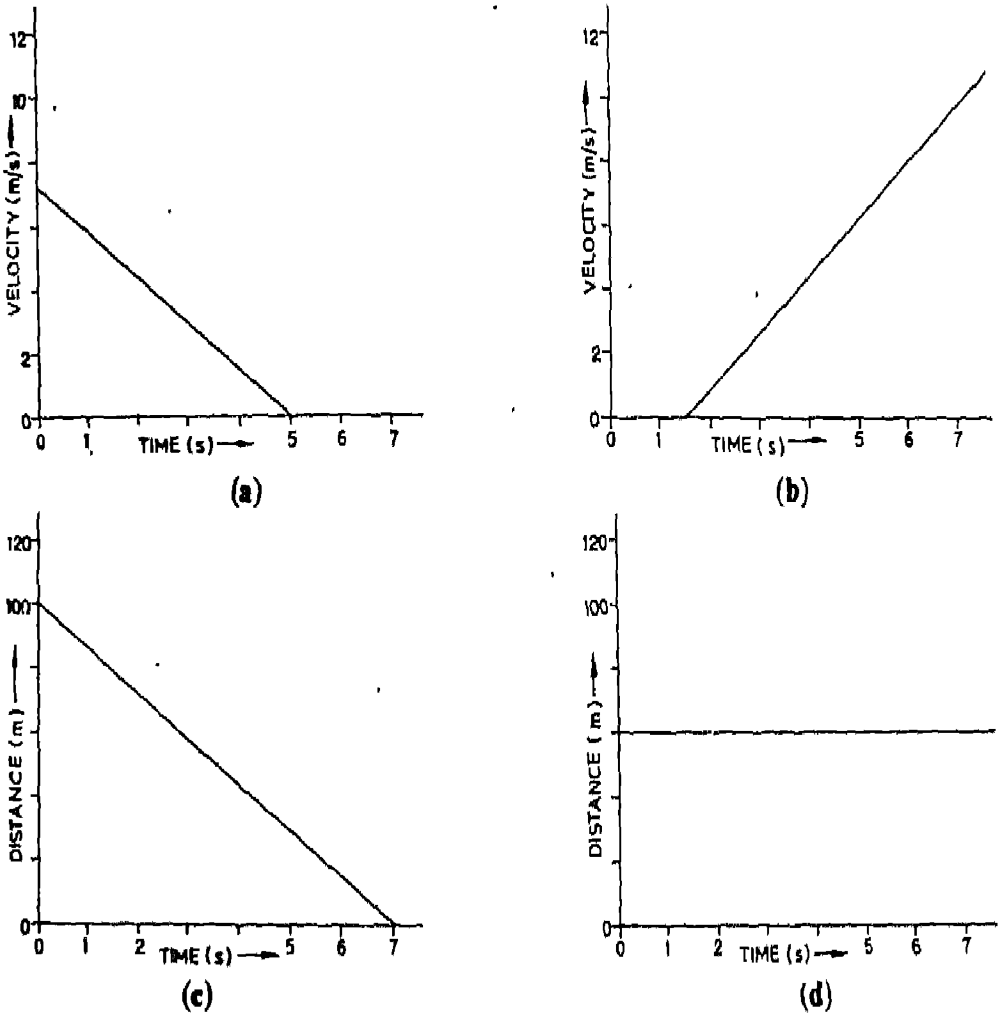


Fig. 4.18-a, b, c, d

22. Take he data given in Fig. 4.1 and find the value of a.

CHAPTER 5

Force and Momentum

5.1 What is Force?

IN THE LAST two chapters we studied how to describe motion of objects. But what makes the objects move? In daily life, we often move objects from one place to another by pushing or pulling them. Sometimes, a moving object may appear to stop by itself, as for example a ball rolling on the ground. But in every case we find that something has to be done to an object at rest in order to make it move, or to stop it, if it is already in motion. We say that a force has been applied. Thus, in general, we may say that a force changes the velocity of an object.

5.2 Force is a Vector Quantity

If you kick a ball lying on the ground, it will go off in a certain direction. If you kick the same ball with about the same force, but from a different direction, it will go off in a different direction. Thus the result of applying a force on a body depends not only upon its magnitude but also upon its direction. Hence, we must consider force as a vector quantity.

Like other vector quantities, we will also represent a force by a line with an arrow-head. The direction of the arrow is the same as that of the force. The length of the line is taken proportional to the magnitude of the force. We note that a force acting on a body cannot be displaced parallel to itself, like other vectors we discussed in Chapter 3. The effect produced on an object by an applied force depends not only on its magnitude and direction but also on the point where the force is applied. Consider a big book lying on a table. If you push the book with nearly the same force with your finger at A or B or C (Fig. 5.1-a,b,c), the result will be different in each case.

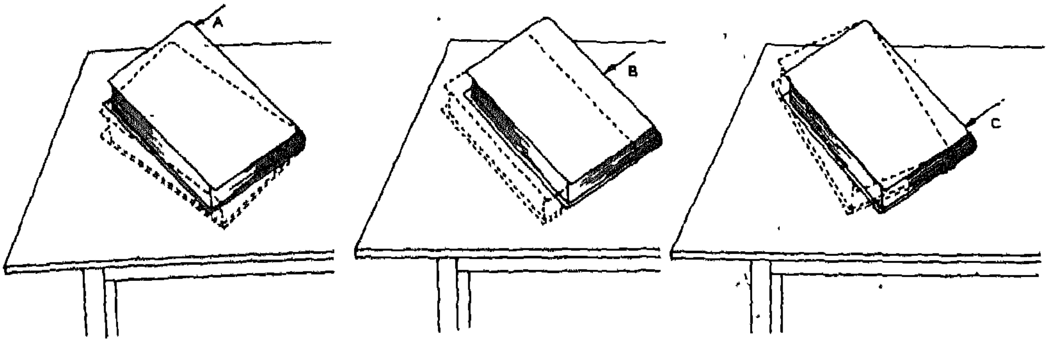


Fig. 5.1-a,b,c: *A force of same magnitude applied at three different points produces different effects.*

If the force is displaced along the line of the force, it produces the same effect on the body. This line drawn through the point of application of the force *in the direction of the force* is called the *line of action of the force* (Fig. 5.2).

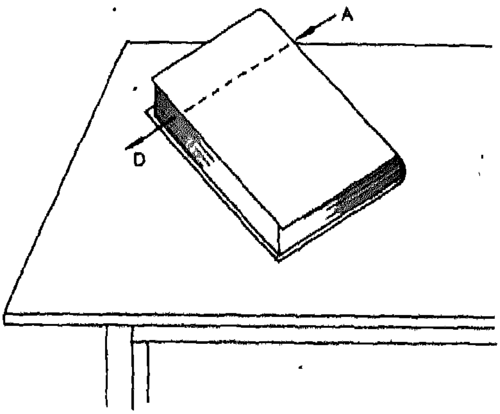


Fig. 5.2: *Line of action of a force.*

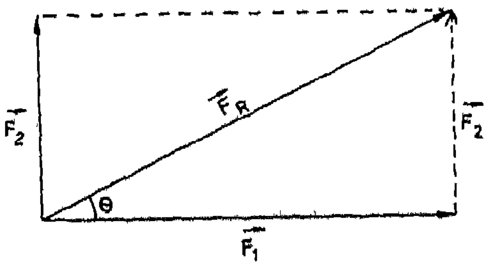


Fig. 5.3: *Resultant force of two forces acting at right angles to each other.*

We have, so far, considered only a single force acting on a body. Sometimes, a large number of forces may be acting simultaneously on an object. If all these forces are acting in such a way that their lines of action pass through one and the same point of the object, then we can replace these forces by a single force which produces the same effect as is produced by all the forces taken together. Such a force is known as the resultant force or simply as the resultant. The resultant force can be found easily with the help of the rules for addition of vectors described in earlier chapters. Here we are describing another method for finding the resultant of two forces at right angles to each other.

Let $\mathbf{F}_1$ and $\mathbf{F}_2$ be two forces acting at a point, at right angles to each other (Fig 5.3). Let $\mathbf{F}_R$ be the resultant force obtained by using the law of parallelogram for addition of vectors:

$$\mathbf{F}_R = \mathbf{F}_1 + \mathbf{F}_2$$

By Pythagoras theorem, the magnitude of the resultant force is given by

$$F_R = \mathrm{F}_R = \sqrt{F_1^2 + F_2^2}$$

If θ be the angle that $\mathbf{F_R}$ makes with the force vector $\mathbf{F_1}$, then making use of trigonometric functions (see Appendix-C) we have

$$\tan\theta = \frac{F_2}{F_1}.$$

Knowing the magnitudes of $\mathbf{F_1}$ and $\mathbf{F_2}$ we can find tan θ and hence θ from tables of trigonometric functions. Note that $\mathbf{F_R}$ makes an angle $90^\circ - \theta$ with $\mathbf{F_2}$.

Replacing the forces acting on an object by their resultant does not mean that the individual forces have ceased to act.

Many other forces, besides the push and pull, exist in nature. For example, objects are attracted towards the centre of the earth because of the force of gravity. Similarly, the force of friction opposes the motion of a body. If a body is at rest, the force of friction opposes the force applied to it to set it in motion. We shall learn more about these and other forces in the next chapter.

5.3 Balanced Forces

If we consider any object, even at rest, in general, a number of forces will be acting on it. Even the nature of different forces may be different. For example, consider a heavy box or crate lying on the ground. You push it gently so that it does not move. There are now four forces acting on the crate (Fig 5.4), viz.,

(i) gravitational force pulling it towards the centre of the earth,
(ii) force exerted by the ground on the crate, which balances the force of gravity and keeps the crate stationary on the ground,
(iii) your push, and
(iv) force of friction opposing the push.

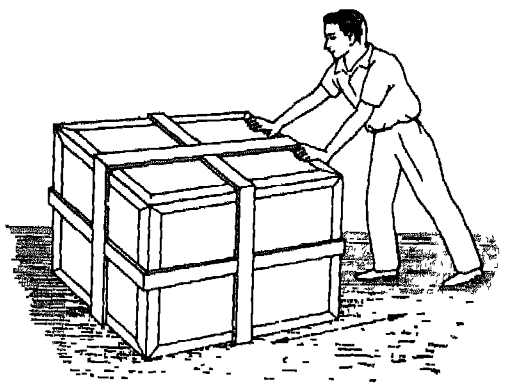


Fig. 5.4: *Pushing a heavy crate along the floor.*

You will note that the nature of each of these forces is different.

When a number of forces act on a body (at the same point), it is always possible to replace these by a single force, called the resultant.

If the resultant of the forces is zero, the forces are said to be *balanced*. An object under balanced forces does not change its position, i.e., it behaves as if no force is acting on it. For example, when you hold a bucket of water steady at some height from the ground, the resultant force is zero. Similarly, in a tug of war, the rope does not move in any direction if the resultant of the forces applied by the members of one team is equal and opposite to that of the other. Thus, we observe that if a number of forces act on a body at rest and these forces are balanced, the

body will continue to be at rest. However, two equal and opposite forces acting on an object may bring about a change in its shape without any change in its position. Action of equal and opposite forces may result in an extension or a compression of a spring, depending on the direction of the forces (Fig. 5.5-a,b). Similarly, if you squeeze an inflated balloon or a rubber ball between your hands, it will get out of shape. Here you apply equal but oppositely directed forces with your hands, so that the resultant is zero.

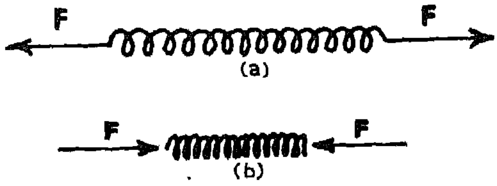


Fig. 5.5: *(a) Extension and (b) compression of a spring by two equal and opposite forces.*

5.4 Unbalanced Forces

Consider the example of the bucket of water again. If you want to lift it up further you will have to apply additional force. If you relax the force, the bucket will move down In the case of two balanced teams in a tug of war, if one team suddenly decides to let go the rope, the other team will be thrown back. Thus, if we begin with balanced forces and then increase or decrease one of them, the resultant force will no longer be zero. In such a situation we say that the forces are *unbalanced. Unbalanced forces produce change in state of motion.* To move an object, you have to push or pull it with a force sufficient to overcome friction.

Consider another example. Suppose we roll a glass marble on a rough floor. Because of the force of friction, its velocity will decrease rapidly and it will come to a stop within a short distance. If the marble is now allowed to roll on a smooth floor (where the force of friction is less) with nearly the same initial velocity, it will cover a longer distance before it stops. If we continue to make the floor smoother thereby reducing friction, the marble, with the same initial velocity, will travel longer and longer distances before stopping. Thus, we may conclude that if friction is reduced to zero the marble will continue to move indefinitely with its initial velocity. Thus, if the force acting on a moving object along its direction of motion is zero, it will continue to move with a constant velocity.

A detailed study of motion led the great English scientist Newton (1642-1727) to formulate three fundamental laws of motion. The first law concerns the effect of balanced forces on bodies. We may state it as follows: *An object continues in its state of rest or of uniform motion along the same direction unless it is acted upon by an unbalanced force.*

Newton's first law of motion implies that all matter possesses a property, which we call *inertia.* Because of this property, matter resists change of velocity (if velocity is zero, the body will be at rest). The greater the inertia of an object, the larger is the force required to bring a change in its state of rest or of uniform motion. The inertia of an object is also a measure of its mass. Two objects are said to have the same mass if they possess equal inertia.

Let us consider a few simple examples to illustrate the property of inertia. While travelling in a bus you would have noticed that if the driver suddenly applies brakes, people fall forward. This is because people travelling in the bus share its motion and when the bus suddenly stops, they still possess the same velocity and are carried forward.

Take a piece of stone weighing about 0.20 kg. Tie it in the middle of a thread about 75 cm long. It should be an ordinary thread, not too strong. Suspend the stone from one end of the string (Fig. 5.6). The other end will hang loosely down. You can now break the thread above the stone or below it, as you desire, by pulling at the lower end. If you give a sharp jerk, the thread will break below the stone. If you increase the pull gradually, the thread will break from above the stone. This can easily be explained on the basis of the property of inertia.

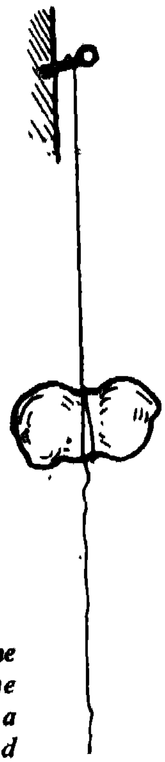


Fig. 5.6: *Stone tied to the middle of a string and suspended from one end.*

5.5 Unbalanced Force and Acceleration

We have talked of unbalanced forces and know that they produce change in motion. We have also studied in Chapter 4 how to measure velocity and acceleration. Newton, through his second law of motion, established a relation between force and change of motion. Newton's second law of motion states:

The acceleration given to a body by an unbalanced force applied to it is directly proportional to the force and inversely proportional to the mass of the body. The acceleration given is in the direction of the force.

In other words, if a force **F** acting on a body of mass m, produces an acceleration **a**, then

$$\mathbf{a} \propto \frac{\mathbf{F}}{m}$$

We may rewrite this as

$$\mathbf{F} = K\, m\, \mathbf{a}. \tag{5.1}$$

where K is the constant of proportionality.

We define the unit force to be that force which produces an acceleration of 1 m/s^2 in a body of mass of 1 kg. This unit of force is called newton (denoted by the symbol N). That is

$$1\ \mathrm{N} = 1\ \mathrm{m/s^2} . 1\ \mathrm{kg} = 1\ \mathrm{kg\ m/s^2}$$

In terms of this unit of force, $K = 1$, in equation (5.1): This leads to the fundamental equation of mechanics

$$\mathbf{F} = m\,\mathbf{a} \tag{5.2}$$

The second law of Newton gives us a method of measuring force in terms of mass and acceleration—quantities we already know how to measure.

Example 1: Calculate the force required to give a toy car of mass 0.25 kg an acceleration of 0.30 m/s^2.

Force, $F = ma$

$= 0.25\ \mathrm{kg} \times 0.30\ \mathrm{m/s^2} = 0.075\ \mathrm{N}.$

Example 2: A resultant force of 10 N gives an acceleration of 5 m/s^2 to a body on a horizontal frictionless surface. What is the mass of the body?

$$\text{Mass of the body} = \frac{\text{Force}}{\text{Acceleration}}$$

$$= \frac{10 \text{ N}}{5 \text{ m/s}^2} = 2 \text{ kg}$$

5.6 Momentum and Force

You might have seen that a cricketer often ducks to a bouncer. Why does he react in this way? It is not the velocity of the ball which frightens him, because if it were a ping-pong ball with the same speed he would not have bothered. It is also not the mass of the ball which worries him, because he handles a stationary ball very comfortably. Our reflex action which makes us move away from the path of a moving vehicle is also of a similar nature. It is the combination of mass and velocity that has a special significance. This combined effect of mass and velocity is taken into account by a physical quantity called *momentum*. Momentum is considered to be a measure of the 'quantity of motion' of an object. It is defined as the product of mass and velocity and is a vector quantity. Thus,

$$\text{Momentum } \mathbf{P} = m\,\mathbf{v} \qquad (5.3)$$

The unit of momentum is kg m/s.

Newton's second law of motion can also be stated in terms of change in momentum: *the rate of change of momentum of an object is equal to the unbalanced force acting on it.* It can easily be established that this statement of Newton's second law is equivalent to the first statement given earlier.

The rate of change of momentum can be determined by dividing the total change in momentum by the time interval during which the change takes place, Thus, according to above statement of the second law,

$$\text{Force} = \frac{\text{Change in momentum}}{\text{Time interval}}$$

$$= \frac{\text{Change in } (m\,\mathbf{v})}{\text{Time interval}}$$

As the mass remains constant, we have

$$\mathbf{F} = m \times \frac{\text{Change in } \mathbf{v}}{\text{Time interval}} = \frac{m \times \text{change in } \mathbf{v}}{t} \qquad (5.4)$$

Since change in $\mathbf{v}$ divided by time interval, t, gives the acceleration '$\mathbf{a}$' we get

$$\mathbf{F} = m\,\mathbf{a},$$

which is the same as equation (5.2). We may rewrite equation (5.4) as

$$\mathbf{F}\,t = m \text{ (change in } \mathbf{v}). \qquad (5.5)$$

The product $\mathbf{F}t$ *is called impulse*. When a force acts for a short duration of time, what is important is the impulse of the force. When you hit a ball with a hockey stick, you give it an impulse. Unit of impulse is newton second (N s).

Example 3: A stationary ball weighing 0.25 kg acquires a speed of 10.0 m/s when hit by a hockey stick. What is the impulse imparted to the ball?

Impuse = mass × change in velocity
= 0.25 kg × (10.0) m/s.
= 2 50 Ns.

Example 4: Calculate the momentum of a ball of mass 100 g moving with a velocity of 15 m/s.

Momentum = mass × velocity
= 0.1 kg × 15 m/s.
= 1.5 kg m/s.

5.7 Action and Reaction

The first two laws of Newton concern only a single body. However, if you examine the examples we have considered above, you will notice that there are always a minimum of two objects involved when a force acts. For example, a force acts on a book lying on the table when you push it. We feel the gravitational force because the earth is there. An electric charge will experience a force only when it interacts with another charged body. Thus, forces always occur in pairs. Newton's third law of motion concerns these pairs of forces. According to this law, whenever two bodies A and B interact (i.e., when they influence each other), the force exerted by body A on B is always equal and opposite in direction to the force exerted by body B on body A.

If the force exerted by one body is called action and that exerted by the other body as reaction, then we may state Newton's third law of motion as: *To every action there is an equal and opposite reaction.*

Consider two spring balances hooked as shown in Fig 5.7. If we pull them in opposite directions, then both will show the same readings

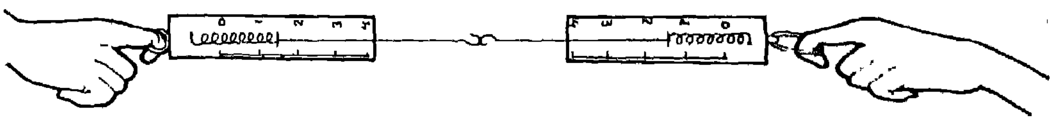


Fig. 5.7: *Two spring balances hooked together and pulled in opposite directions.*

When we walk on the ground we push the ground with our feet. The ground, in its turn, pushes the feet and that provides the necessary force for us to move (Fig. 5.8). This may appear strange, but it is the correct situation. If you ever tried to walk on ice or on a wet smooth floor, you will realise that without friction it becomes impossible to walk.

Stand near a wall facing it and push it with both your hands (Fig. 5.9-a). You will find that the wall also pushes you with an equal but opposite force. If you do not believe this, ask a friend to stand facing you and now you two join hands and push each other (Fig. 5.9-b). Is not the situation the same as when you were pushing the wall? If you hit the wall with your fist, the wall

Fig. 5.8: *Boy walking on the ground.*

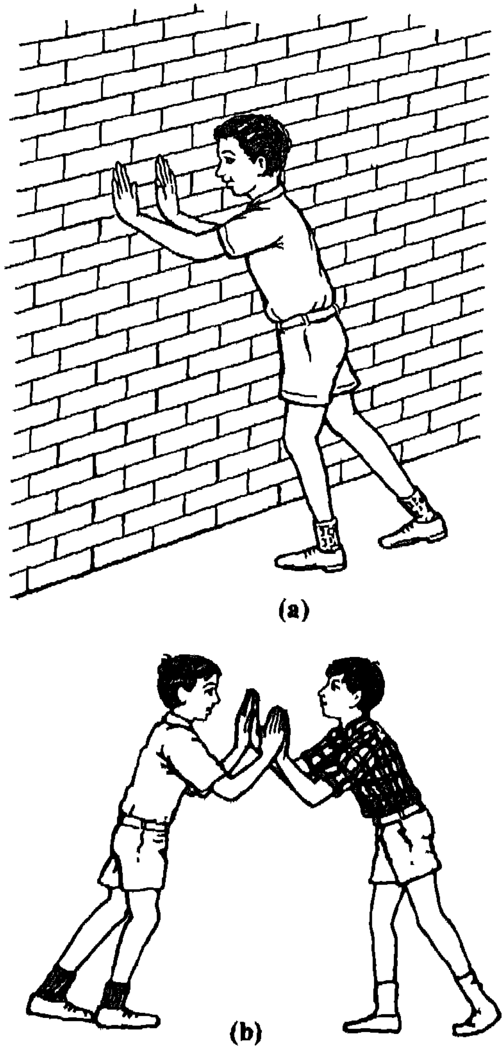


Fig. 5.9: *(a) Boy pushing against a wall. (b) Two boys pushing against each other.*

will hit you back with the same force.

It is very important to remember that action and reaction act on different bodies. If they were to act on the same body, the resultant would be zero and nothing would move.

5.8 Conservation of Momentum

We will now consider a simple problem which has very wide applications: the problem of collision of two balls. Let the mass of ball A be m_1 and its initial velocity (i.e., velocity before collision) be $\mathbf{u}_1$. Let the mass of ball B be m_2 and its initial velocity $\mathbf{u}_2$. Let us further suppose that the interaction in the form of a collision between these objects lasts for a time t. After the collision, let the velocities of the two balls be $\mathbf{v}_1$ and $\mathbf{v}_2$ respectively (Fig. 5.10). If there are no external forces present, then the rate of change of momentum of ball A will be $\frac{m_1(\mathbf{v}_1-\mathbf{u}_1)}{t}$. Similarly, the

rate of change of momentum of ball B will be $m_2 (\frac{\mathbf{v}_2 - \mathbf{u}_2}{t})$. If the force exerted by ball B on A is $\mathbf{F}_1$ and that exerted by A on B be $\mathbf{F}_2$, then according to Newton's second law of motion:

$$\mathbf{F}_1 = \frac{m_1 (\mathbf{v}_1 - \mathbf{u}_1)}{t} \qquad (5.6)$$

and
$$\mathbf{F}_2 = \frac{m_2 (\mathbf{v}_2 - \mathbf{u}_2)}{t} \qquad (5.7)$$

Now according to Newton's third law of motion, $\mathbf{F}_1$ and $\mathbf{F}_2$ should be equal in magnitude but opposite in direction. That is,

$$\mathbf{F}_1 = - \mathbf{F}_2 \qquad (5.8)$$

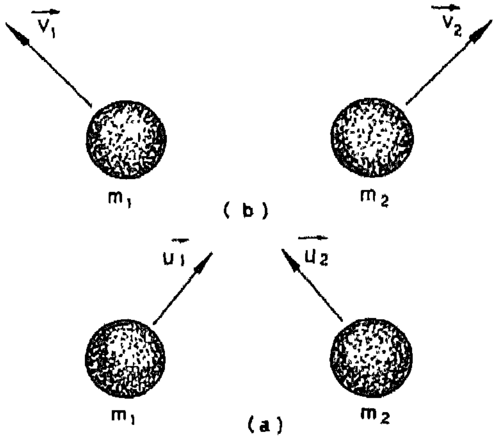


Fig. 5.10-a,b: *Collision between two balls.*

Therefore, from equations (5.6), (5 7) and (5.8), we get,

$$\frac{m_1 (\mathbf{v}_1 - \mathbf{u}_1)}{t} = - \frac{m_2 (\mathbf{v}_2 - \mathbf{u}_2)}{t}$$

or, $$m_1 (\mathbf{v}_1 - \mathbf{u}_1) = - m_2 (\mathbf{v}_2 - \mathbf{u}_2)$$

or, $$m_1 \mathbf{u}_1 + m_2 \mathbf{u}_2 = m_1 \mathbf{v}_1 + m_2 \mathbf{v}_2 \qquad (5.9)$$

Now $(m_1\mathbf{u}_1 + m_2\mathbf{u}_2)$ is the sum of the momenta of the balls before the collision and $(m_1\mathbf{v}_1 + m_2\mathbf{v}_2)$ is their total momentum after the collision. Thus, we find from equation (5.9) that the sum of the momenta of the interacting objects before and after the collision is the same. In other words, the total momentum remains unchanged. The generalisation of the above conclusion leads us to one of the most important and universal laws of physics, *the law of conservation of momentum.* This law can be stated as follows: *The total momentum of any group of objects is always the same unless they are acted upon by some external force*

The recoil of a gun, the propulsion of rockets, jet planes or Diwali rockets involve the principle of conservation of momentum. In a jet engine, gases at very high speed are ejected through a nozzle at the rear of the engine. The escaping gases carry some momentum. The engine therefore acquires an equal and opposite momentum to that carried by the gases. The momentum gained by the engine provides the necessary force to push the rocket or the plane in the forward direction.

Example 5: A bullet of mass 0.01 kg is fired from a gun weighing 5.0 kg. If the initial speed of the bullet is 250.0 m/s, calculate the speed with which the gun recoils.

Initial momentum of the system is zero. Therefore, by the law of conservation of momentum.

250.0 m/s × 0.01 kg + 5.0 kg × (speed of the gun) = 0

or, speed of the gun = −0.50 m/s,

i.e , the gun recoils in a direction opposite to the one in which the bullet is fired.

5.9 Moment of a Force

We learnt that an object is accelerated when acted upon by an unbalanced force and the acceleration is in the direction of the applied force. It was, however, assumed that the body was completely free to move. However, there are situations when a body may be fixed at a point or along an axis. For example, consider a door hinged along one side. Similarly, a wheel may be free to rotate about an axis passing through its centre, which is held fixed.

Let us perform a simple experiment. Open a door slightly. Now to close it, apply a force with one finger at point C near the handle (Fig. 5.11). Open the door again as before and now apply the force at the mid-point B of the door. Repeat this by applying the force at point A near the hinge of the door (Fig. 5.11). You will find that it becomes more difficult to close the door as the point of application of force moves from C to A.

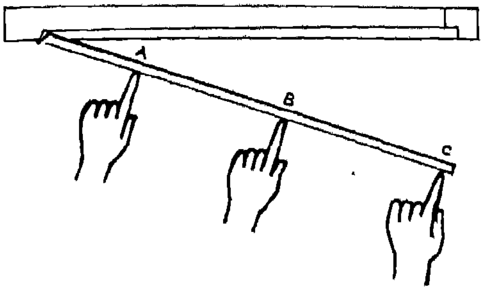


Fig. 5.11: *Closing a door by applying force at different points.*

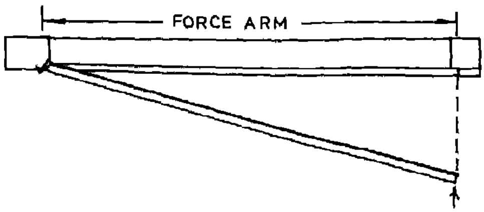


Fig. 5.12: *Force-arm in a few cases.*

From the above observations, we find that the turning effect of a force increases as the distance of the point of its application from the axis of rotation increases. The perpendicular distance between the point of application of the force and the axis of rotation is called the force-arm or the lever-arm (Fig. 5.12). The turning effect of a force must also be proportional to the magnitude of the applied force. The turning effect of a force is, therefore, given by the product of the magnitude of the force and the length of the corresponding force-arm This product is called *moment of the force or torque.* If F be the magnitude of the force and l the length of the force-arm, then the torque or the moment of the force is given by

$$\tau = F \times l \tag{5.10}$$

(τ is Greek letter tau). If the force is measured in newton and force-arm in metre, the unit of torque is newton metre or Nm. (We may just mention here that torque is a vector quantity. Its direction is along the perpendicular to the plane containing the force and the force-arm vectors. If the rotation produced is in the anti-clockwise direction, the torque is taken to be positive while if the rotation produced is in clockwise direction, then it is taken to be negative.)

We have seen that two equal and opposite forces acting at the same point balance each other and, therefore, no change in position of the body results. Let us now consider the case when two equal forces act at two different points on the same object. Let us first consider the case when the two forces are parallel and point in the same direction.

Take a metre scale and make a hole on the centre line a little towards one edge. Suspend it from this hole as shown in Fig. 5.13. The scale should stay horizontal. Now suspend a known weight, say 0.1 kg, at a convenient mark on the scale, say 10 cm. The scale will begin to tilt in the anti-clockwise direction Hold the scale so that it does not tilt too much Next suspend an equal weight on the other side of the point of suspension and adjust its position such that the scale again becomes horizontal. Note the mark on the scale where the second weight is suspended. Find the distance of the two weights from the centre of suspension They must come out to be the same (Fig. 5.13).

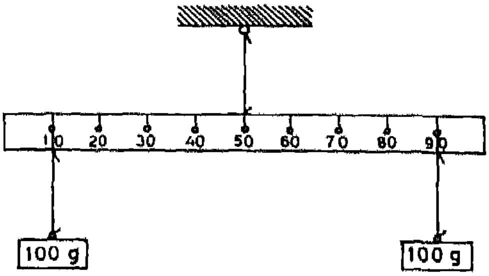


Fig. 5.13: *Metre scale balanced with equal weights on either side of the centre.*

Now try to balance the metre scale by suspending unequal weights on the two sides. Note the weights and the corresponding distances from the point of suspension of the scale (i.e., the length of the two force-arms).

Now for each set of readings, calculate the product of the weight and the corresponding force-arm for each side. You will find that the two products are equal for each set of readings. In other words, in the balanced condition, the moment of the force in one direction is equal to the moment of the force in the opposite direction. This is known as the principle of moments. In general, if a force F_1 acting at a distance l_1 from the point of rotation is balanced by a force F_2 acting at a distance l_2, then

$$F_1 \times l_1 = F_2 \times l_2 \qquad (5.11)$$

The principle of moments is utilised in the construction of physical balances. In a balance the two arms are made of equal length and the two pans have equal masses. When there are no weights on the pans, the moments of the forces acting on the two sides are equal and opposite and the balance is said to be in equilibrium. When an object to be weighed is kept on one pan, the beam of the balance rotates in one direction. We then place known weights on the other pan till the beam again attains equilibrium, i.e., it becomes horizontal. Since the force-arms are equal, the weights in the two pans have also to be equal.

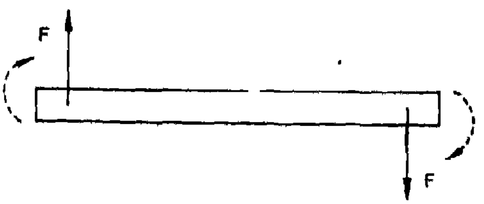


Fig. 5.14: *A couple acting on a body.*

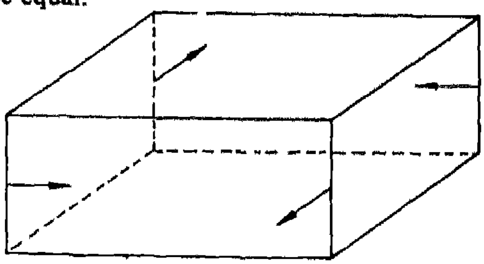


Fig. 5.15: *Two equal and opposite couples acting on a body.*

5.10 Couple

Two equal and opposite forces acting at different points of a body are said to form a couple The moment of a couple is given by the magnitude of the force and the perpendicular distance between them (Fig. 5.14). It can be seen that the action of a couple tends to rotate the object in one direction. If two equal and opposite couples act simultaneously on an object, they balance each other and no rotation is produced (Fig. 5.15). This is similar to the case in linear motion when two equal and opposite forces acting at a point produce a zero resultant.

ACTIVITIES

1. Take a rubber band about 10 cm in length. (If you have two small ones, join them by looping one through the other.) Pass this band through the handle of a medium size pair of scissors (or any other similar object) and hold the ends up as shown in Fig. 5.16-a. The rubber band will hardly stretch, indicating that the weight of the scissors is not very large. Now bring the hands apart as shown in Fig. 5.16-b. You

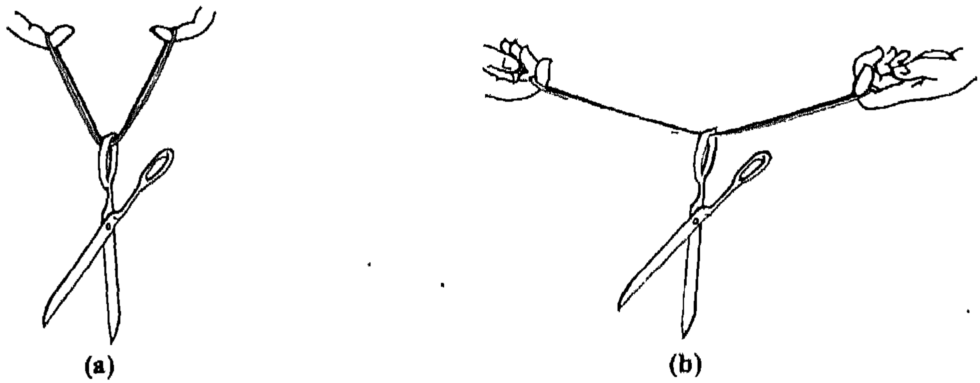


Fig. 5.16: *(a) A pair of scissors suspended from a rubber band. (b) San. with rubber band stretched out.*

will now find that to keep the band almost straight needs considerab e force and the rubber band is stretched. (A weak band may even break. Also be careful that the scissors do not fall on the ground and break or hurt someone.) Analyse the forces in the two cases.

2. Take a tumbler and place it on the table or on an even floor. Place a thick card on it so that the mouth of the tumbler is covered. Next place a 50 p coin or a rupee coin on the card near its centre (Fig. 5.17-a). Can you remove the card in such a way that the coin is not disturbed and it falls into the glass? It is easily done if you flick hard the card with your finger, as shown in Fig. 5.17-b.

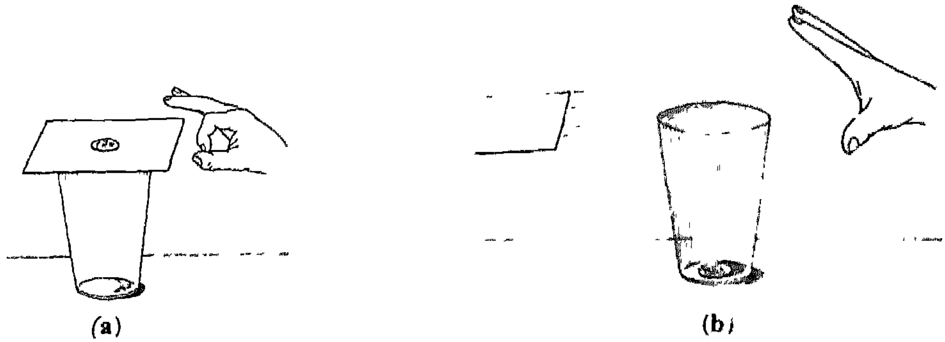


Fig. 5.17-a,b: *A card and a coin over a tumbler.*

3. Fill a balloon with air. Release it. What do you observe? Does it fly off? As the air rushes out of the mouth of the balloon, it gains momentum in the opposite direction.

QUESTIONS AND PROBLEMS

1. How can two forces of 3 N and 4 N combine to give forces of (a) 7 N, (b) 1 N, and (c) 5 N?
2. Calculate the acceleration produced in the following cases:
   (a) Force of 24 N acting on a body of mass 12 kg.
   (b) Force of 24 N acting on a body of mass 6 kg.
   (c) Force of 48 N acting on a body of mass 12 kg.

   [Ans. (a) $2 m/s^2$ (b) $4 m/s^2$ (c) $4 m/s^2$]
3. Plot a graph between acceleration, a, and mass, m, for a given force F (Take F=100 N, and 10 values of m in the range 1 to 100 kg. Find a and plot the ten points and obtain the graph.)
4. Calculate the force needed to produce an acceleration of (a) 6 m/s^2 and (b) 9 m/s^2 in a body of mass 4 kg.

   [Ans. (a) 24 N, (b) 36 N]
5. By how much does the momentum of a body of mass 5 kg change when its speed
   (a) decreases from 20 m/s to 0.20 m/s,
   (b) increases from 30 m/s to 40 m/s.

   [Ans. (a) 99 kg m/s (decrease), (b) 50 kg m/s (increase)]
6. A metre scale is balanced at its centre and mass of 0.5 kg is suspended from one of its ends. At what distance from the centre must the following masses be suspended to obtain equilibrium:

(a) 0.5 kg, (b) 1.0 kg, (c) 2.5 kg and (d) 10 kg?

[**Ans.** (a) 50 cm, (b) 25 cm, (c) 10 cm, (d) 2.5 cm]

7. Can one obtain equilibrium with a mass of 0.1 kg instead of 0 5 kg in question No. 6?

8. Find out the resultant of two forces of 80 N and 50 N acting at right angles to each other by (i) graphical method (ii) using trigonometric functions

[**Ans.** magnitude $10\sqrt{89}$ N, direction $\tan^{-1} 5/8$ w r.t. 80 N force]

9. Explain how a quantitative definition of force is given by Newton's second law Discuss what is implied by saying that the acceleration of a body gradually decreases to zero.

10. A driver accelerates his car first at the rate of 1.8 m/s^2 and then at the rate of 1.2 m/s^2. Calculate the ratio of the force exerted by the engine in the two cases.

[**Ans.** 3.2]

11. Indicate the action and reaction in each of the following cases:

(a) A man standing on the ground.

(b) A stone suspended with a thread.

12. A man in a circus show jumps from a height of 10 m and is caught by a net spread below him. The net sags down 2 m due to his impact. Find out the average force exerted by the net on the man to stop his fall. Take the mass of the man to be 60 kg and consider the value of acceleration during his free fall as 10m/s^2. (**Hint:** find the acceleration produced during the period the net sags down by 2m.)

[**Ans.** 3,000 N]

13. A bullet of mass 5 g on hitting a sand bag suspended in air gets embedded in it. If the velocity of the bullet be 900 m/s just before it hits the bag, find out the speed with which the sand bag will move due to the impact of the bullet. The mass of the sand bag is 50 kg.

[**Ans.** $\simeq$ 0.09 m/s]

14. A target of mass 400 g moving with a horizontal speed of 10 m/s is hit by a bullet of mass 0.01 kg moving in the opposite direction. If both the bullet and the target come to rest after the collision, calculate the velocity of the bullet at the time of striking the target.

[**Ans.** 400 m/s]

CHAPTER 6

Forces in Nature

WE HAVE LEARNT in the previous chapter that an unbalanced force acting on an object may either bring a change in its velocity or its shape. We also studied about the laws governing the action of forces on objects. However, so far we have been considering only the magnitude and direction of forces without being concerned about their origin. In this chapter we shall study, in some detail, about some of the forces that exist in nature.

6.1 Force of Gravity

According to Newton's second law a change in velocity of an object can take place only due to the action of an unbalanced force. However, some of our observations seem to contradict the above conclusion about forces. For example, if you release a ball from your hand, it immediately starts falling towards the ground even though you did not push it (Fig. 6.1). It is a common experience that most objects fall towards the earth once they are set free at some height. Does it mean that there is something wrong with Newton's second law? The answer is no. The free fall of objects is due to the action of a force which is experienced by all objects, including all living beings. This force is the *gravitational force* of the earth. The earth attracts all objects towards its centre. It is due to this force that all objects tend to acquire a position which is nearest to the centre of the earth, unless they are held up by some other force. For example, when we lift a bucket of water, a force has to be applied to balance the force of earth's gravity.

6.2 Law of Gravitation

Gravitation is not a property of earth alone It is a property common to all objects possessing mass. It means that all material objects exert force of gravitation on all other objects in this universe. For example, a piece of stone attracts all other objects including the earth. The piece of stone in turn also experiences the gravitational force of all other objects This universal character of gravitation was first understood by Sir Isaac Newton (1642-1727). Newton carefully studied the motion of planets and presented his ideas about gravitation in the form of a law known as Newton's law of gravitation. According to this law *every mass in this universe attracts every other mass with a force which is directly proportional to the product of the two masses and inversely proportional to the square of the distance between them.* The force of gravitation acts along the line joining the centre of mass of the two bodies. (We have, therefore, not used the vector notations here. The distance between objects is measured from their centres of mass. The centre of mass of an object is a point where all its mass is assumed to be concentrated. For objects having regular shape like circular discs, spheres, cubes, etc., the centre of mass is at their geometrical centre.)

Suppose there are two objects of mass m_1 and m_2 separated by a distance r. According to the first part of Newton's law of gravitation, the force F between them will be in proportion to the product $m_1 m_2$ and according to the second part, it will be proportional to $\frac{1}{r^2}$ .Combining these two, the force of gravity F will be proportional to $\frac{m_1 m_2}{r^2}$

i.e. $$F \propto \frac{m_1 m_2}{r^2}$$

or $$F = G \frac{m_1 m_2}{r^2} \qquad (6.1)$$

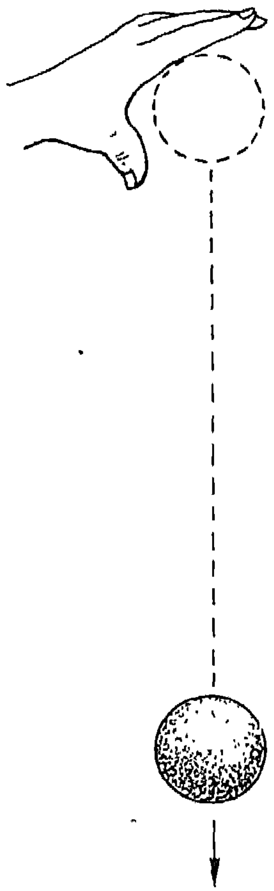


Fig. 6.1: *A ball released from a height will fall towards the ground.*

where G is the constant of proportionality and is known as the gravitational constant. If mass is measured in kilogram, distance in metre and force in newton, the value of G is approximately equal to 6.7×10^{-11} Nm^2/kg^2. We note that the value of this gravitational constant G is very small. It indicates that the force of gravity is a very weak force.

Let us consider the force of gravitation between two boys standing at a distance of 1 m from each other. Let the mass of each boy be 40 kg. i.e., $m_1 = m_2 = 40$ kg and $r = 1$m. The force of gravitation F between the boys will be given by equation (6.1). Substituting the values of m_1,

m_2, r and G in this equation, we get

$$F = \frac{6.7 \times 10^{-11}\left(\frac{\text{Nm}^2}{\text{kg}^2}\right) \times 40\ (\text{kg}) \times 40\ (\text{kg})}{(1)^2\ (\text{m}^2)}$$
$$= 10.7 \times 10^{-8}\text{N}$$

It means each boy will exert a force on the other equal to 10.7×10^{-8} N which is an extremely small force. Similarly, the gravitational force between any two objects on the earth is very small

On the other hand, the mass of the earth being very large, its force of gravitation is sufficiently large to make all objects near its surface to fall towards it.

The force of gravitation exists everywhere in the universe It is one of the fundamental forces in nature. In particular, it is responsible for the existence of our solar system. Near the surface of the earth this force is responsible for holding our atmosphere, for the flow of rivers, for rainfall and above all, for holding us firmly on to the ground.

Example 1: Calculate the force of gravity due to the earth on a 40 kg boy standing on the ground.

Here
$$m_{earth} = 6 \times 10^{24}\ \text{kg}$$
$$m_{boy} = 40\ \text{kg}$$
$$r = \text{radius of the earth}$$
$$= 6.4 \times 10^3\ \text{km.}$$

Hence, from equation (6.1)

$$F = \frac{6.7 \times 10^{-11}\left(\frac{\text{Nm}^2}{\text{kg}^2}\right) 6.0 \times 10^{24}\ (\text{kg}) \times 40\ (\text{kg})}{(6.4 \times 10^6)^2\ (\text{m}^2)}$$
$$\simeq 4 \times 10^2\ \text{N.}$$

This is a sufficiently large force.

(Note that the force of gravity between two boys calculated above is 10^{-10} **times smaller.)**

6.3 Acceleration due to Gravity

We note that the force of gravity on any object on the surface of the earth is proportional to the mass of the object, m. We may, therefore, write this force as

$$F = \frac{G m_{earth}\ m}{R^2_{earth}} \tag{6.2}$$

and this force is directed towards the centre of the earth. In the above **equation** G and

mass of the earth m_{earth} are constants and if we consider radius of the earth R_{earth} also to be a constant, then the factor

$$\frac{Gm_{earth}}{R^2_{earth}}$$

will be a constant. Hence equation (6.2) can be written as

$$F = \text{Constant} \times m \tag{6.3}$$

If we compare equation (6.3) with the expression for Newton's second law, i.e., $F = m\ a$, then the constant factor in the above equation should represent an acceleration. This acceleration is known as the *acceleration due to gravity* and it is represented by the symbol g. Substituting the known values of G, m_{earth} and R_{earth}, we get

$$g = \frac{G\ m_{earth}}{R^2_{earth}}$$
$$= 9.8\ \text{m/s}^2 \simeq 10\ \text{m/s}^2 \tag{6.4}$$

This acceleration is in the direction of the line joining the body to the centre of the earth.

(The value of acceleration due to gravity is not a constant at all points on the surface of the earth. This is so because the earth is not a perfect sphere and, therefore, the value of R_{earth} is not the same at all places on its surface.)

Equation (6.3) can now be rewritten as

$$F = m\ g \tag{6.5}$$

The force of earth's gravity acting on an object of mass m is also known as its weight. The weight is, therefore, measured in the same units as force, i.e., newton. If we lift a mass of 1 kg, the force required would be nearly equal to 10 N which is its weight. This force is often referred as one kilogram weight (kg wt). Since the value of acceleration due to gravity g can change slightly from place to place, the weight of an object also varies accordingly. The mass of the object, on the other hand, always remains the same.

We further note that g, the acceleration due to gravity, is independent of the mass of the body on which the force of gravity acts. Thus, *all bodies fall with equal acceleration on the surface of the earth.*

6.3.1 Mass of an Object. The mass of an object was defined by us in Chapter 5 as a measure of its inertia. The larger the inertia an object has, the greater is its mass. The mass of an object defined in terms of its inertia is known as its *inertial mass.*

Newton's law of gravitation provides us with another definition of mass. The mass of an object defined in this manner is known as its *gravitational mass.* Although gravitational mass

and inertial mass of an object, by definition, are two different quantities, yet the two have same value for the object Thus, in all measurements involving mass no distinction is made between the inertial mass and the gravitational mass of an object.

To understand the concept of gravitational mass let us consider three objects A_1, A_2 and B. Let the distance between A_1 and B and that between A_2 and B be the same. The force of gravitation, F_1, between objects A_1 and B will be given by

$$F_1 = \frac{G\,(\text{mass of object } A_1) \times (\text{mass of object B})}{(\text{distance between } A_1 \text{ and B})^2}$$

Similarly, the force F_2 between objects A_2 and B will be

$$F_2 = \frac{G\,(\text{mass of object } A_2) \times (\text{mass of object B})}{(\text{distance between } A_2 \text{ and B})^2}$$

If force F_1 is equal to force F_2, then from the above equations we get

$$\text{mass of object } A_1 = \text{mass of object } A_2$$

This means that if two objects A_1 and A_2 when placed at the same distance from a third object B experience the same gravitational force, then their gravitational masses will be equal. If in the above example we consider object B to be the earth, then the two objects will be said to possess the same gravitational mass if the forces of earth's gravity on them are equal. (We assume that the two objects are at the same distance from the centre of the earth.)

The above idea of comparing masses is used by us almost daily. For example, when we buy one kilogram of sugar, the shopkeeper keeps a standard 'kilogram weight' (mass of 1 kg) on one pan of the balance and sugar on the other. He then adjusts the quantity of sugar till the beam of the balance is horizontal. In balanced position, the force of earth's gravity on one pan becomes equal to that on the other. Therefore, the mass of the sugar on the pan will be equal to that of the standard 'kilogram weight' placed in the other pan.

We note that the balance only tells us that the force of earth's gravity on the object is equal to that on the standard weight placed on the other pan. This balance will not be disturbed if we move the whole set-up to any other place on the earth or even take it to the moon where the force of gravity is much less than on the earth's surface. In all cases, the gravitational force on the object and on the standard weight will increase or decrease equally and the beam will remain horizontal. Thus, the mass of an object does not change from place to place. The weight, on the other hand, may change because the force of gravity on it may undergo a change from one place to another.

6.4 Measuring Gravitational Force

In order to study forces in some detail, we must be able to measure them. We look for a property of materials which changes in direct proportion to the applied force. A very

convenient device is a spring balance. It is found that the change in length of a spring is directly proportional to the force acting on it (Fig. 6.2-a, b, c).

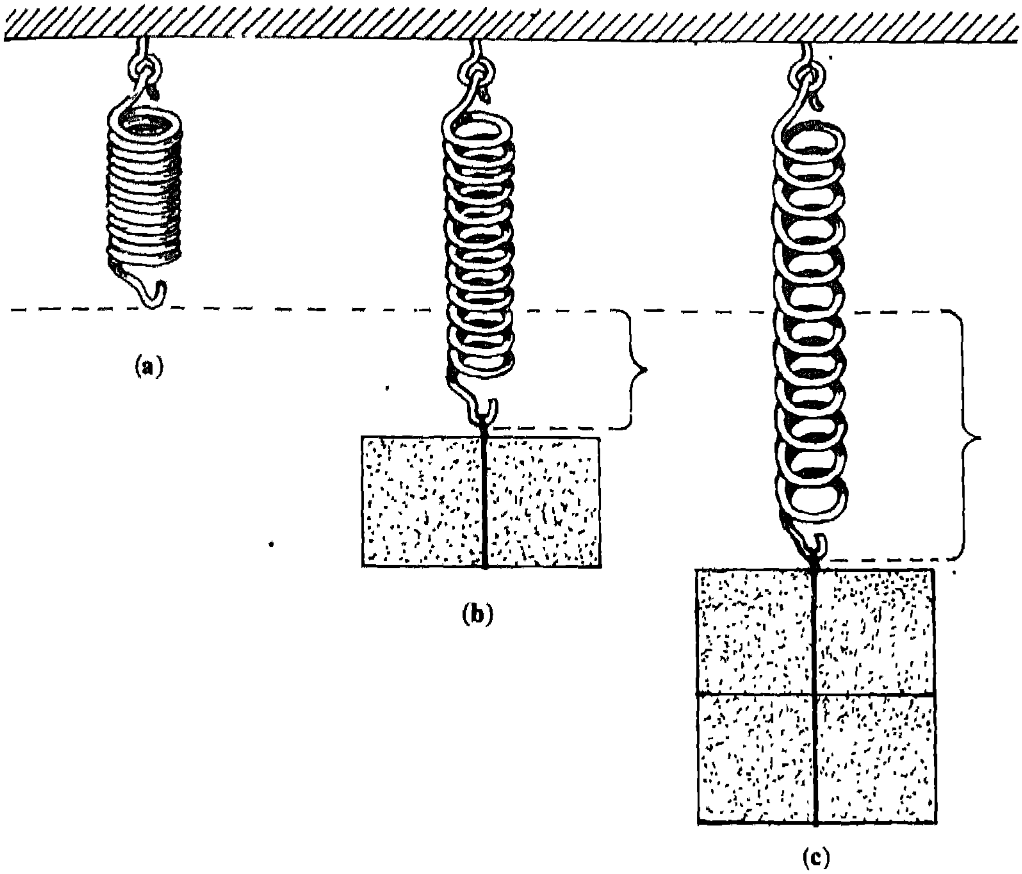


Fig. 6.2-a, b, c: *The extension of a spring is directly proportional to the applied force.*

Spring balances are very well suited for measuring the force of gravity on a body. In one type of spring balance, the extension of the spring measures the force (Fig. 6.3-a), while in another type (Fig. 6.3-b), it is the compression which measures this force. Extension type spring balances have to be supported at the top and the other type firmly supported on their base. Some spring balances are marked to measure force in newton (symbol N). However, as you would have noticed, most spring balances are marked in kilogram (or gram). This is because in daily life we use the two words mass and weight interchangeably. Even in science we 'weigh' an object on a physical balance, when we are actually determining its mass. We know that on the surface of the earth the value of 'g', acceleration due to gravity, is almost constant. Hence mass and weight differ only by a constant factor which can be seen from the solution to

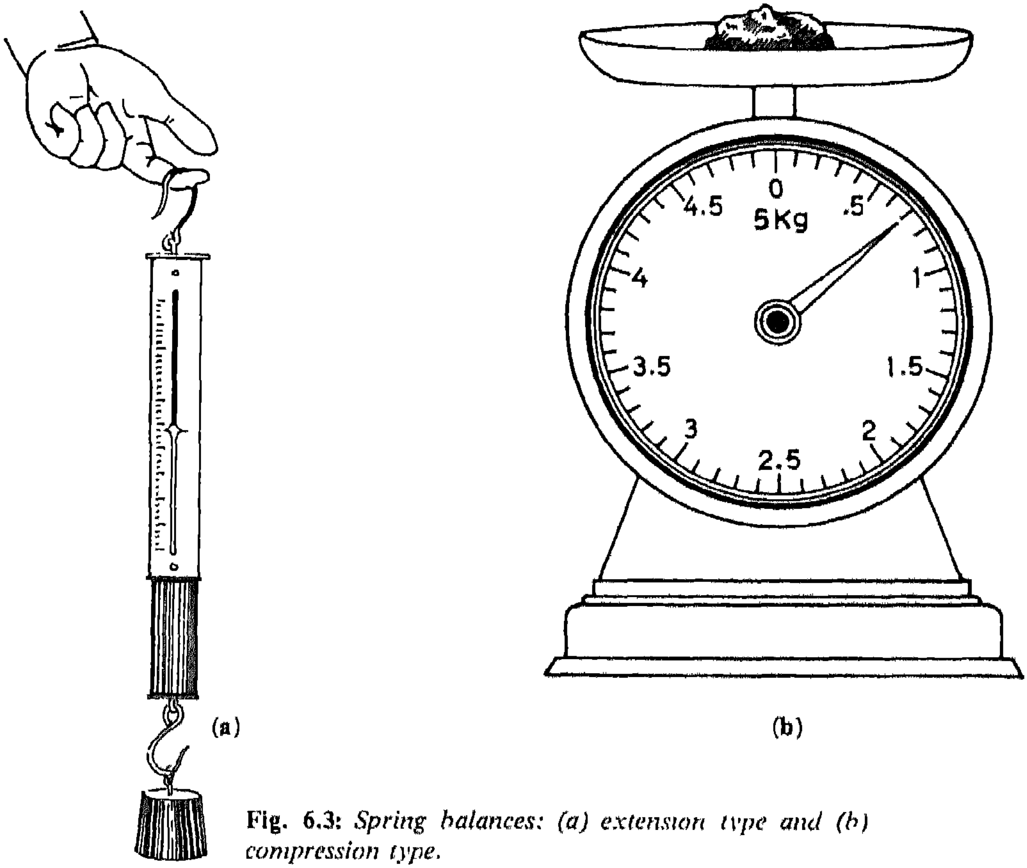


Fig. 6.3: *Spring balances: (a) extension type and (b) compression type.*

Example 1 We buy our things in terms of mass, and therefore even people who manufacture spring balances graduate them in kilogram (or gram). You must, however, remember that what operates a spring balance is a force and not just mass. If we were to use our spring balances for weighing on the moon, the extension produced in the spring would only be about 1/6th of what it produces on the earth, because the value of acceleration due to gravity on the surface of the moon is only about 1.6 m/s^2, i.e., 1/6th of the value on the surface of the earth.

6.5 Electric Force

After combing dry unoiled hair with a plastic comb, take it near tiny pieces of paper. You will observe that the comb attracts these pieces of paper. If you perform this experiment during night in darkness, and when the air is dry, you will also be able to see tiny sparks between the hair and the comb. A plastic pen rubbed with a piece of woollen cloth will also be able to attract tiny pieces of paper. An inflated rubber balloon rubbed on woollen cloth will stick to any wall. A glass rod rubbed with a piece of silk will attract pith-ball suspended by a thread (Fig. 6.4). Materials made of nylon fibre also exhibit similar effects. These are all examples in which a new

kind of force comes into play. This force is the *electric force*.

The electric force between two charged bodies is directly proportional to the product of the quantity of charges on each body and inversely proportional to the square of distance between them. In other words, if a body with charge q_1 is placed at a distance r from another body with charge q_2 in vacuum, then the force F between them acting along the line joining the two charges will be

$$F \propto \frac{q_1 q_2}{r^2}$$

or $$F = \frac{K q_1 q_2}{r^2} \text{ newton} \qquad (6.6)$$

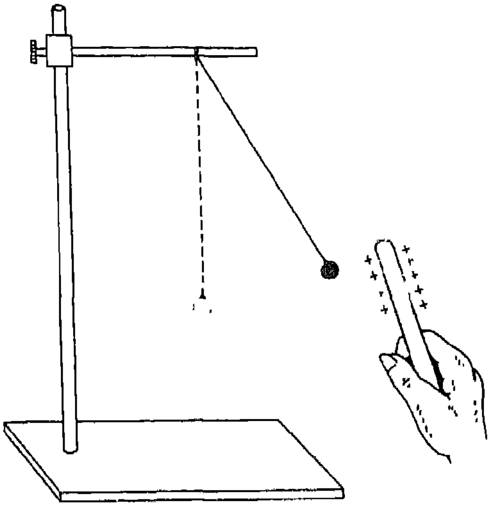


Fig. 6.4: *Pith-ball is attracted by a charged rod.*

where K is a constant of proportionality and is equal to 9×10^9 Nm^2/C^2 Here C stands for coulomb, the unit of electric charge. We can use equation (6.6) to define a coulomb of charge. If the force between two equal charges separated by a distance of 1m in vacuum is 9×10^9 N, then each charge is 1 coulomb.

If q_1 and q_2 are both positive or both negative, then the force between them will be positive. *Positive force implies repulsion between similar charges.* On the other hand, the force will be negative if one of the charges is positive and the other negative. *A negative force indicates attraction.* Thus, an electric force can be attractive as well as repulsive, whereas gravitational force is always attractive.

Example 2: Find the force between two charged bodies A and B separated by a distance of 0.5 m in vacuum, given that body A has a positive charge of 20.0 microcoulomb (μC) while body B carries a negative charge of 50.0 microcoulomb (μC).

We are given that

The charge on body A (q_A) = 20.0 μC
The charge on body B (q_B) = $-$50 0 μC
Distance r = 0.5 m

The force between charged bodies is given by equation (6.6). Substituting the values of the different quantities in equation (6.6), we get

$$F = \frac{(9\times10^9 \text{ Nm}^2/\text{C}^2)(20\times10^{-6}\text{C})(-50\times10^{-6}\text{C})}{(0.5\text{m})^2}$$

$$= -\frac{9 \times 20 \times 50}{25 \times 10^{-2}} \times 10^{-3} \text{ N}$$

$$= -\ 36.0 \text{ N}$$

The negative sign indicates that force is attractive. You will observe that coulomb is a very big unit of charge. Even two charges, one of $-50.0\ \mu C$ and another of $20.0\ \mu C$ separated by a distance of 0.5 m in vacuum, exert a force of 36.0 N on each other. It is equivalent to a force of about 3 6 kg weight.

You will note that we have calculated the force between two charges in vacuum, i.e., in space free from any material bodies. This is important because the force between charges gets modified if any material body lies between them. This does not happen in the case of gravitational force.

Electric force is also one of the basic forces of nature and is responsible for a large number of phenomena taking place in everyday life.

6.6 Magnetic Force

It is common experience that magnets attract pieces of iron. However, if we take two bar magnets, say A and B, and bring one end of magnet A close to one end of magnet B, the force between the two ends may be either repulsive or attractive. Suppose it is repulsive. If we now bring the same end of magnet A close to the other end of magnet B, they will attract each other (Fig. 6.5-a, b).The two ends of a bar magnet are called its poles. From the above observations, it

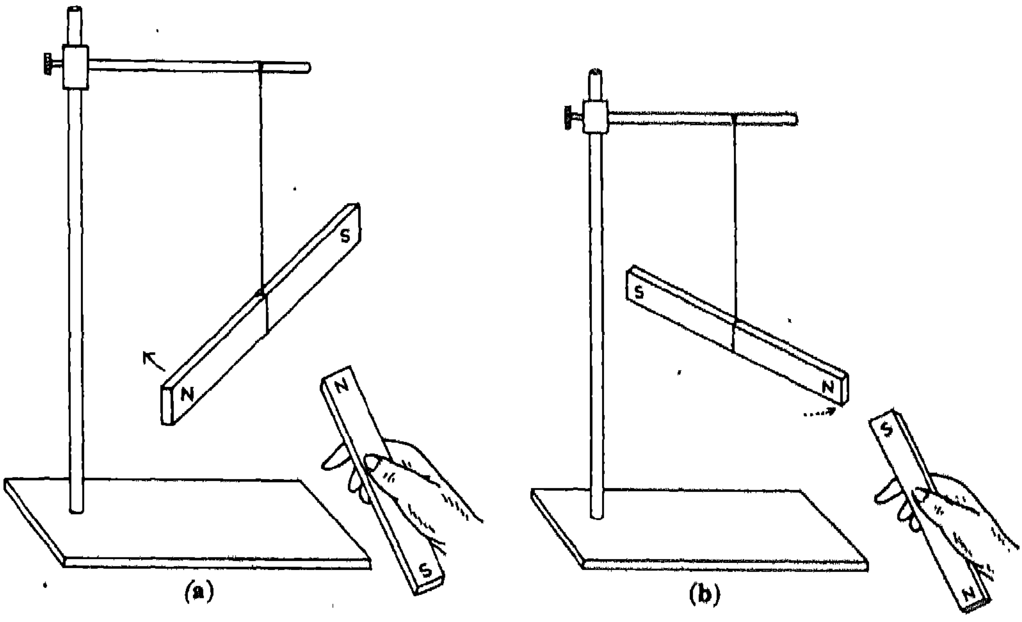


Fig. 6.5.-a, b: *Like poles of a magnet repel while unlike poles attract.*

is clear that two different kinds of poles must exist. One we call the south pole and the other we call the north pole. Like poles repel each other and unlike poles attract. Both the poles attract pieces of iron. The force between magnetic poles or between a magnetic pole and pieces of iron

is called a *magnetic force.*

The magnetic force between two poles depends directly on the product of their strengths and inversely on the square of the distance between them. Thus, if m_1 and m_2 be the two pole strengths, and if they be separated by a distance r, the magnetic force is given by

$$F=\mu \frac{m_1 m_2}{r^2}$$

where μ is a constant of proportionality.

The earth also exhibits certain magnetic properties. It can be demonstrated very easily by suspending a bar magnet from its middle by a thread, so that it is free to rotate in a horizontal plane. If there are no iron objects or any other magnet in the immediate neighbourhood of the suspended magnet, it will quickly align itself along the north-south direction, with the north pole pointing towards north.

The magnet soon realigns itself in the same direction if it is disturbed. This observation can be explained by assuming a giant bar magnet lying along the axis of rotation of the earth with its south pole pointing towards the geographical north pole and its north pole pointing towards the geographical south pole (Fig. 6.6). Since the north pole of the freely suspended magnet points towards north we also call it the north seeking pole. Similarly, the south pole of the magnet is also called the south seeking pole.

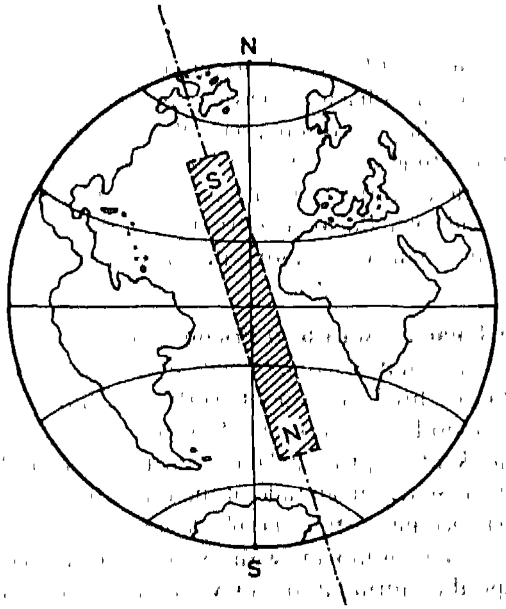


Fig. 6.6: *Earth as a magnet*

6.7 Force of Friction

So far we have considered three different forces, all of which operate between bodies which may be widely separated from each other. However, there is another type of force which acts only between bodies in contact. This is the force of friction.

We know that a bicycle slows down if we stop pedalling. A ball rolling freely along level ground gradually loses speed and finally stops. If we give a sudden push to a book lying on a table, it will slide for some distance and then stop. The decrease in the speed of the body in all these cases is due to a force known as the *force of friction.* Force of friction comes into play whenever one surface moves over another, be it rolling or sliding. The unevenness or roughness of the surfaces is *the major factor which contributes to the force of friction. If an apparently smooth surface is*

examined under a powerful microscope, it will appear irregular with lots of bumps and depressions.

Let us consider what happens when a small force is applied on an object resting on a table. Let the direction of this force be parallel to the surface of the table. If the body does not move, it would mean that an equal and opposite force comes into being (Fig. 6.7). This opposing force is

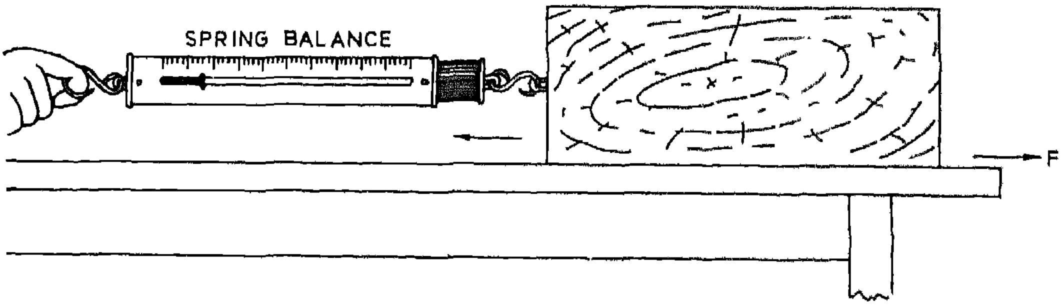


Fig. 6.7: *For a stationary object lying flat on a surface, the force of friction F balances the applied force.*

the force of friction. If we go on increasing the applied force, the force of friction also goes on increasing till a limiting value is reached. When the applied force exceeds this limiting value, the object begins to move.The effective force acting on the object will be the difference in the magnitude of the applied force and the limiting force of friction. It must be remembered that friction continues to act on the body even when it is in motion. When the applied force is withdrawn, the force of friction continues to act and ultimately brings the object to rest. That is why a ball rolling along the ground stops after some time.

6.8 Factors on which Friction Depends

Some simple activities will help you to discover the factors on which friction depends. Place a brick on a smooth surface as shown in Fig. 6.8 or a wooden block of about 1 kg mass on a smooth glass surface at least 60 cm long. Tie a piece of thread round the block and attach the hook of a spring balance into the loop. Pull the spring balance along the surface. Slowly increase the magnitude of the force till the block starts moving. Note the reading of the spring balance just before the block starts moving.

Keep it moving with a slow uniform speed for about 30 to 40 cm. It is difficult to keep the speed uniform but try a few times. Never let the block stop during this motion. The reading of the spring balance may fluctuate slightly during this motion. You note the mean value.

Next, put one more block over the one lying on the floor. Repeat the experiment and find the force required to start the two blocks moving and also to keep them moving with a constant speed (Fig. 6.9).

Now wrap one block in a sheet of paper and repeat the experiment. Determine the force required to start the block moving and also that required to keep it in uniform motion.

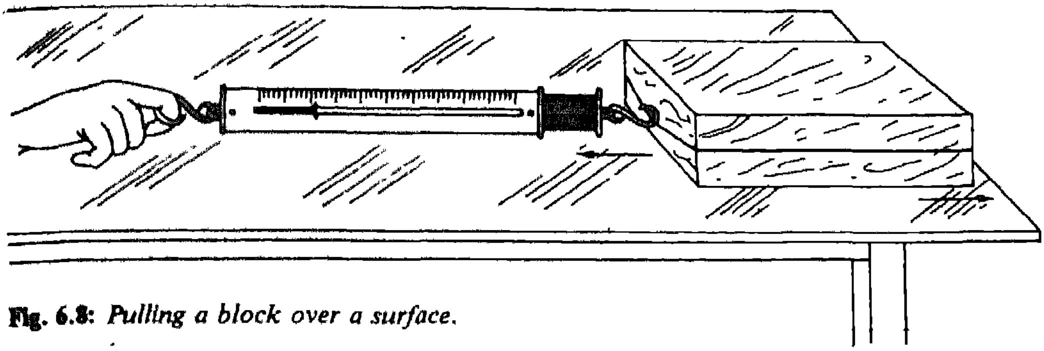


Fig. 6.8: *Pulling a block over a surface.*

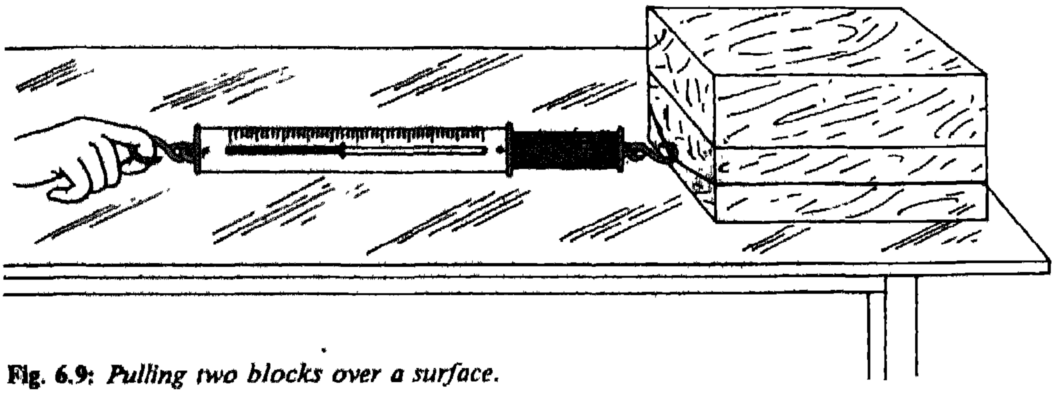


Fig. 6.9: *Pulling two blocks over a surface.*

Next, place the block on one of its other faces, as shown in Fig. 6.10. In this case the surface area of the block in contact with the surface will be less than that in the first case (Fig. 6.8). Again find the force required to start the block moving and also that needed to maintain it in uniform motion.

Lastly, repeat the experiment after putting the block over four or five pencils with round cross-sections. Note the readings of the spring balance when the block is moving with a constant speed (Fig. 6.11).

If you compare the values of the forces required to keep the block moving uniformly in different cases, you will find that the force of friction depends upon the following factors:

(1) The force of friction on an object just before it starts moving is always more than that when it is moving. The force of friction is equal to the applied force if the object slides with a constant speed.

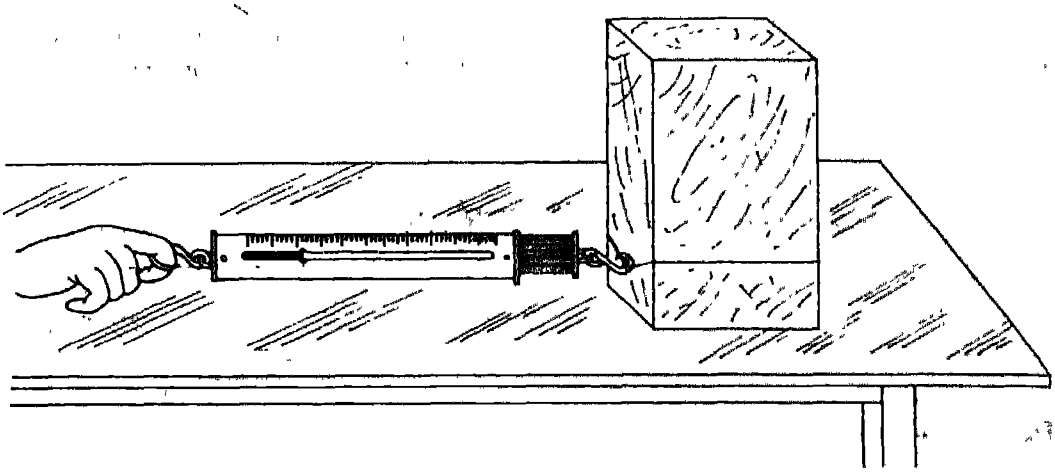


Fig. 6.10: *Pulling a block along a surface when it is standing on a smaller base.*

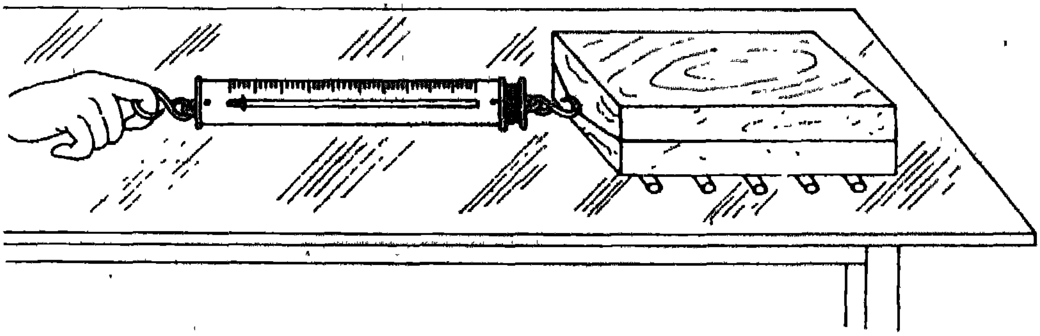


Fig. 6.11: *A block placed on round pencils being pulled along a surface.*

(2) The force of friction is directly proportional to the weight of the body sliding over the surface.

(3) The force of friction depends upon the nature of surfaces in contact. For smooth surfaces, the force of friction is smaller.

(4) For the same weight of the body, the force of friction is independent of the area of contact.

(5) If a body rolls instead of sliding, the force of friction will be less, i.e., rolling friction is less than sliding friction.

In many situations friction plays a very valuable role whereas in others it is disadvantageous. We are able to walk on the ground because of friction. Nails and screws hold

things together because of friction. In lighting a match stick, in sewing clothes, in applying brakes to a bicycle or a car or a train, friction comes to our help. However, moving parts in a machine wear out and consume more power because of friction. Cars and aeroplanes are streamlined to reduce air friction. Heavy loads are moved by placing them on rollers.

We can control friction to some extent. Machine parts are made very smooth. Use of lubricants and ball-bearings further reduces friction. In some cases, we have to increase friction, as in bicycle or car tyres. The tyre surfaces are made corrugated and rough to provide better grip on the road and to prevent their slipping.

QUESTIONS AND PROBLEMS

1. Explain the difference between mass and weight.
2. Calculate the force exerted by the earth on the moon.
   Take mass of the earth $= 6 \times 10^{24}$ kg, mass of the moon 7.4×10^{22} kg.
   Distance of the moon from the earth $= 3.84\times10^{5}$ km.
   [Ans. 2.01×10^{20}N]
3. Calculate the value of acceleration due to gravity on the surface of the moon. Take mass of moon 7.4×10^{22} kg and its radius 1740 km.
   [Ans. $a \simeq 1.65$ ms^{-2}]
4. State the law of gravitation and discuss how the force depends upon distance. If the distance between two objects is doubled, what will happen to the force between them? If the distance is halved, what happens to the force?
5. Show that if two objects of different masses are released simultaneously from the same height, they will reach the ground at the same time. (We neglect air resistance.)
   [**Hint:** Use equations of motion derived in Chapter 4.]
6. Calculate the force of attraction between a proton and an electron separated by a distance of 0.5×10^{-10}m.
   Charge of the electron $= -1.6\times10^{-19}$C, charge of the proton $= +1.6 \times 10^{-19}$ C.
   [Ans. $F \simeq 9 \times 10^{-8}$N]
7. Calculate the force between two charges each of 1C, separated by a distance of 10 m.
   [Ans. $F \simeq 9 \times 10^{7}$N]
8. If the same force as given in problem 7 existed as the force of gravitation between the earth and a body of mass M on its surface, what would be the value of M?
   [Ans. $M \simeq 9 \times 10^{6}$kg]
9. Calculate the force of gravity on a body of mass 100 kg placed on the surface of the earth.
   [Ans. $F \simeq 1{,}000$ N]
10. What is magnetic force? How will you demonstrate that earth behaves like a huge magnet?

11. What is force of friction? Describe on what parameters of a body sliding over a horizontal surface does it depend.
12. Give reasons for the following:
    (a) A freely suspended magnet always points in the north-south direction.
    (b) The force of gravitation due to the earth produces retardation when a body moves up, and produces acceleration when the same body moves down. On the contrary, why does the force of friction always produce retardation in the motion of a body?
13. A heavy trunk is lying on the floor. A boy applies a force of 100 N to pull it, but fails. Then a man pulls it by a force 300 N, but fails. Then an athlete applies a force of 600 N and is able to pull it. What force does prevent it from moving in the first two cases? What conclusions can you draw about the force from these three observations?
14. Two boys together try to lift a bucket full of water. Each applies a force of 200 N, the two forces being perpendicular to each other, as shown in Fig. 6.12. Find the magnitude and direction of the resultant force acting on the bucket. What should they do to increase the resultant force?

[Ans. Vertically upward, $200\sqrt{2}$ N]

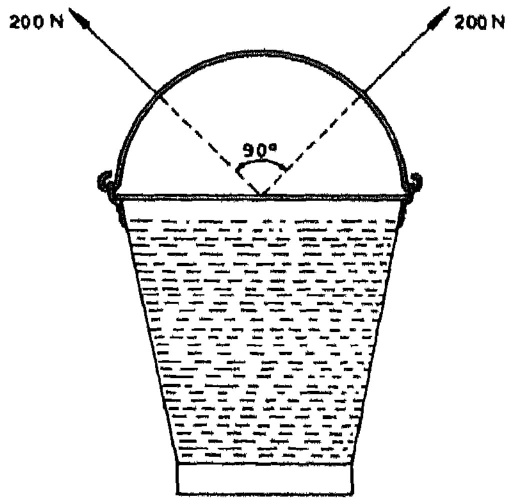


Fig. 6.12

15. A body of weight 600 N rests on the floor of a lift. If the lift begins to fall freely under gravity, what is the force with which the body presses on the floor?
16. A man throws a ball weighing 0.5 kg vertically upwards with a speed of 10 m/s.

What will be its initial momentum? What would be its momentum at the hightest point of its flight?

[**Ans.** 5 kg ms^{-1}; zero]

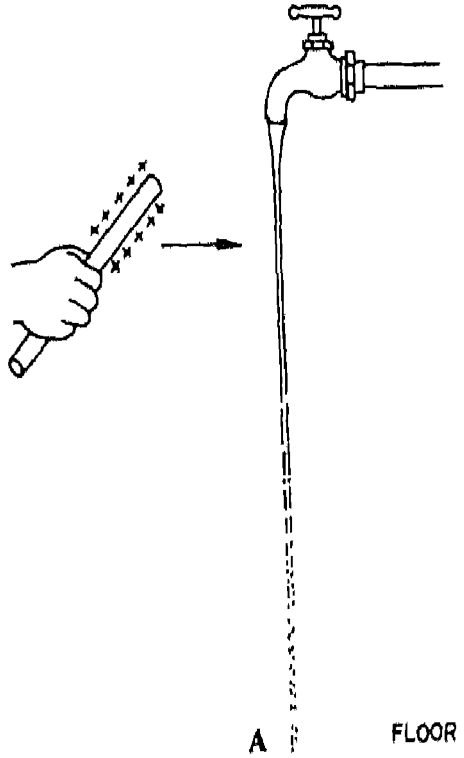


Fig. 6.13

17. A stream of water is falling down from a water tap, as shown in Fig. 6.13. It reaches the ground at a point A. What will happen to the stream of water if a glass rod with positive electric charge on it is gradually brought near it? What will happen to the stream if the rod has negative electric charge instead of the positive?

CHAPTER 7

Work and Energy

7.1 Work

IN THE PREVIOUS chapters, we discussed the relationship between force and motion and studied the action of a force on an object. The action of a force on an object can also be described in terms of another physical quantity called 'work'. The word 'work' is frequently used in our daily life to imply different things, e.g., class work, home work, etc. However, in physics, 'work' has a very definite meaning. We say that *work* is done on an object *only if both* the following conditions are satisfied:

(i) *a force acts on the object*, and

(ii) *the point of application of force moves due to the application of the force.*

No work is done if any of the above conditions is not satisfied. For example, no work is done by the force of gravity on a suitcase if it is held stationary at a point above the ground. This is so because the force of gravity acting on the suitcase does not move it. (Here we are not considering the work done by the muscles in holding the suitcase.) We define work as the product of the force, F, and the distance, s, over which the force continues to act on the object. We measure the distance along the direction of the force. Thus,

work done = force × distance moved along the direction of the force

or
$$W = F \times s \tag{7.1}$$

When the force is measured in newton and distance in metre, the unit of work is newton metre. This unit has a special name, joule (symbol J).

1 joule (J) = 1 newton metre (Nm).

We note that work is a scalar quantity. Suppose an object of mass 1.0 kg is lifted vertically through a distance of 1.0 metre (Fig. 7.1). Force required to do so will be equal to the weight of the object, i.e., 1.0 kg $\times$ 9.8 m/s^2 or 9.8 N and hence

$$\text{Work done } (W) = 9.8 \text{ N} \times 1.0 \text{ m} = 9.8 \text{ Nm} = 9.8 \text{ J}$$

Similarly, if a force of 10 N is required to push an object through a distance of 5 m (Fig. 7.2), the work done is

$$W = 10 \text{ N} \times 5 \text{ m} = 50 \text{ Nm} = 50 \text{ J}.$$

Now consider a *frictionless* horizontal table on which we push an object. The object will continue to move even when the applied force is withdrawn. No work is done on the object after the initial push, though the object keeps on moving. This is so because no force acts on the object.

In many cases movement of the object may not be in the direction of the applied force. For

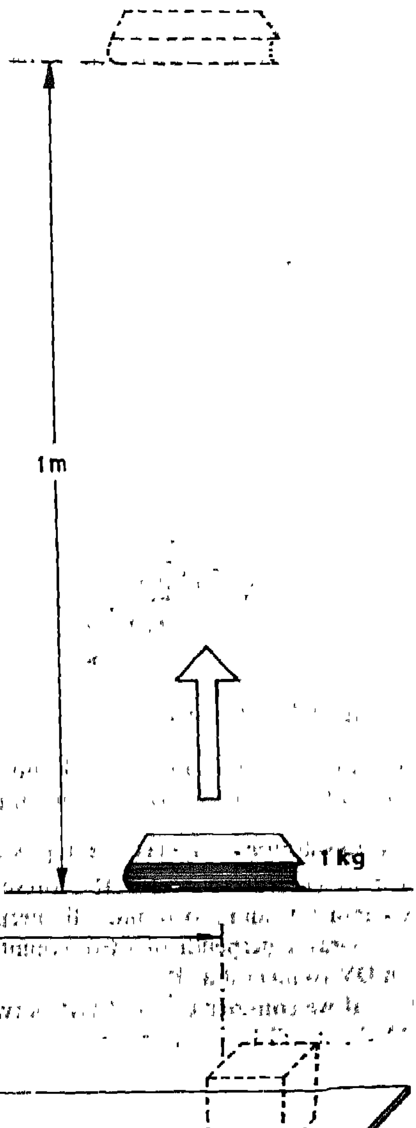


Fig. 7.1: *Lifting a mass of 1 kg vertically up by 1m.*

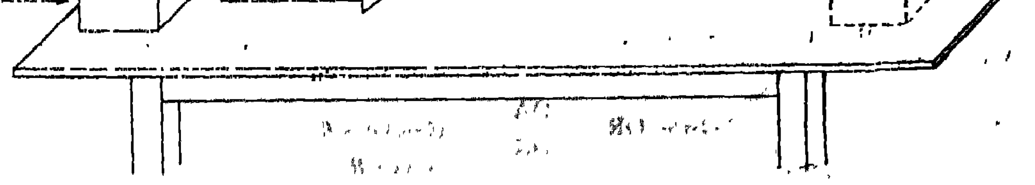


Fig. 7.2: *Work is done in pushing an object along the ground against the force of friction.*

example, in Fig. 7 3 we see a child pulling a toy. The force applied by him is along the direction of the string, whereas the toy moves along the ground. To calculate the work done, we must

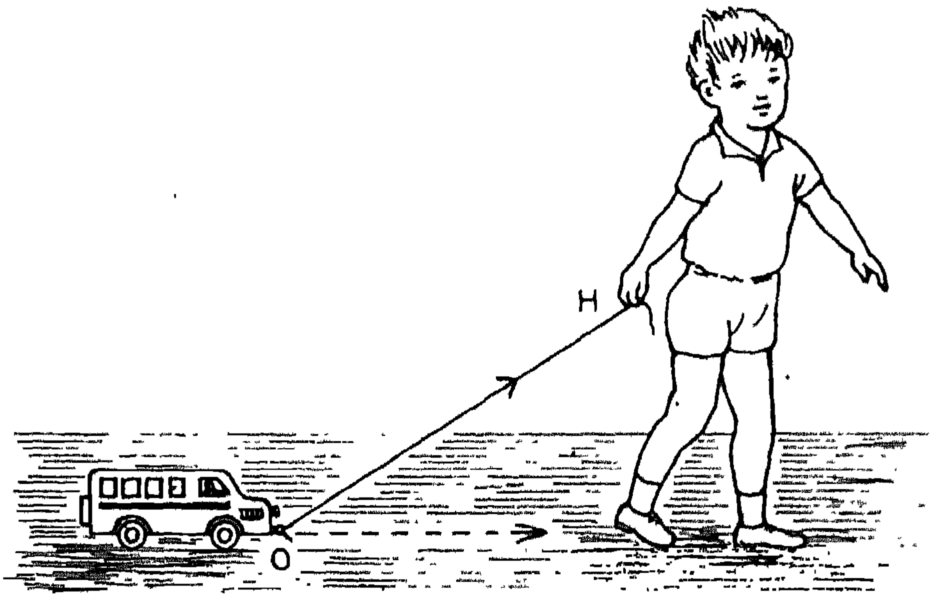


Fig. 7.3: *Child pulling a toy.*

know the effective force along the direction of motion of the toy. To do this, we must learn how to resolve a force vector F in two mutually perpendicular directions.

7.2 Resolution of a Vector along two Mutually Perpendicular Directions

Let us consider a vector **R** represented by $\vec{OR}$ in Fig 7.4. Suppose we wish to find its components along two mutually perpendicular directions OX and OY.

Draw a perpendicular from point R on OX to meet it at A and draw another perpendicular on OY to meet it at B.

If we consider $\vec{OA}$ and $\vec{OB}$ as two vectors, then by the rule of addition of vectors their resultant will be the vector $\vec{OR}$,

$$\vec{OA} + \vec{OB} = \vec{OR}.$$

We say that vectors $\vec{OA}$ and $\vec{OB}$ are the two components of the vector $\vec{OR}$ along OX and OY respectively. The magnitude of the vector $\vec{OA}$ can be written as

$$OA = OR \frac{OA}{OR} = (OR)\cos\theta$$
$$= R\cos\theta$$

where θ is the angle which OR makes with OX and $\cos\theta$ has been defined in Chapter 5.

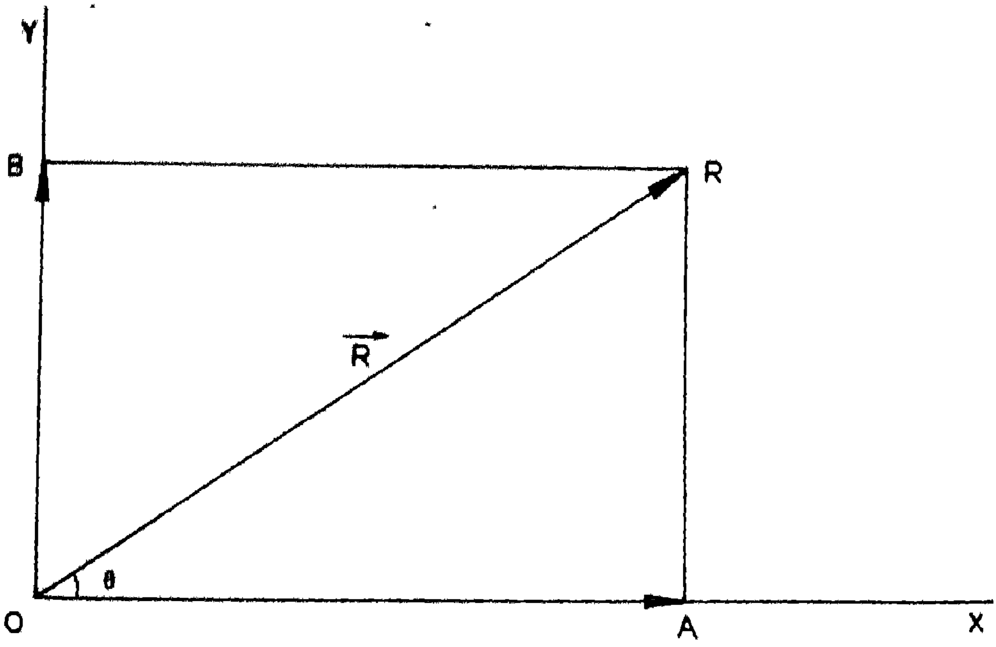


Fig. 7.4: *Resolution of vector* **R** *along two mutually perpendicular directions OX and OY.*

Similarly, the magnitude of the component

$$OB = OR \frac{OB}{OR} = (OR)\sin\theta$$
$$= R\sin\theta$$

Thus, the magnitude of the two components of the vector **R** along OX and OY are $R\cos\theta$ and $R\sin\theta$ respectively. (Note that a vector in two dimensions has two components. A three-dimensional vector has three components.)

It is important to note that the same vector can be resolved along any two mutually perpendicular directions as shown in Fig. 7.5 where OX' and OY' are another set of perpendicular axes and OA' and OB' are the corresponding components in this frame.

$$OA' = OR \frac{OA'}{OR} = R\cos\theta'$$

$$OB' = OR \frac{OB'}{OR} = R\sin\theta'$$

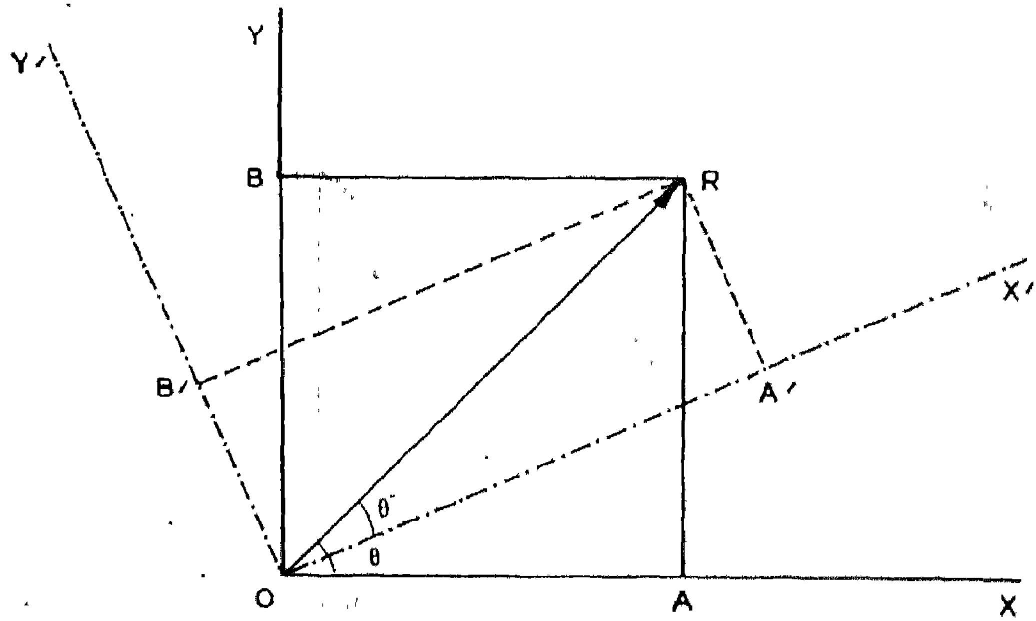


Fig. 7.5: *A given vector can be resolved along any two mutually perpendicular directions.*

7.3 Work Done by a Force Acting Obliquely

In the example of the child pulling the toy considered above, we can now calculate the work done by the force on the toy. It will be the product of the component of the applied force along the ground and the distance moved by the object. The force, F, applied by the child is along the direction OH of the string. The component of this force along the ground will be $F\cos\theta$ where θ is the angle which the force vector makes with the ground. If the toy moves through a distance, s, then the work done will be

$$W = s\ F\cos\theta \tag{7.2}$$

It is obvious that the work done in this case will be less than Fs because only a fraction of the force, F, does the work. In view of the above, we can modify the definition of work in the following manner. *The work done by a force is equal to the product of the component of the force along the direction of motion of the object and the distance through which the point of application of the force moves.*

It may be interesting to note that if the force acts in the direction in which the object moves, then the component of the force along this direction is the magnitude of the force itself since $\theta = 0$, $\cos\theta = 1$. On the other hand, if the object moves at right angles to the direction of the

force, the component of the force along the direction of the force becomes zero and so the work done would be zero.

Tie a small stone to one end of a metre-long string. Swing it in a circle in a horizontal plane above your head (Fig. 7.6). In this case, the force on the stone is along the string, i.e., along the radius of the circle. The stone moves in a circular path and at every moment it is moving at right angles to the direction of the applied force. Hence, in this case, the work done by the applied force is zero. There are many examples of such motion in nature. The earth going round the sun is an example of such a motion. Artificial satellite going round the earth is another example.

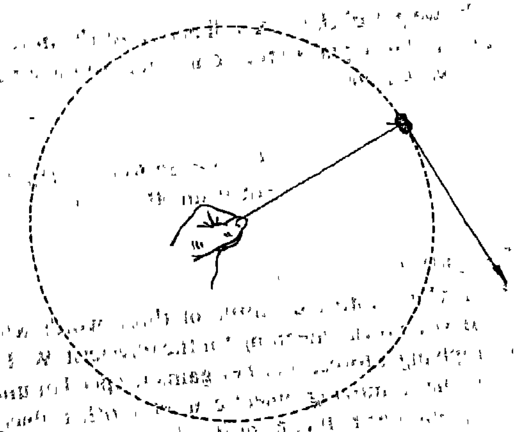


Fig. 7.6: *A boy whirling a stone tied to a string.*

The artificial satellite is held to the earth by the force of gravity, which acts along the line joining the two. The satellite moves along the circumference of the circle, i.e., at right angles to the direction of the force.

Example 1: A box weighing 15 N slides down from the top of an inclined plane making an angle of 30° with the horizontal. Calculate the work done by the force of gravity in moving the box 5 m along the plane. Assume that the force of friction is zero.

Given:

F = weight of the box = 15 N

$\theta = 30°$, $s = 5$ m

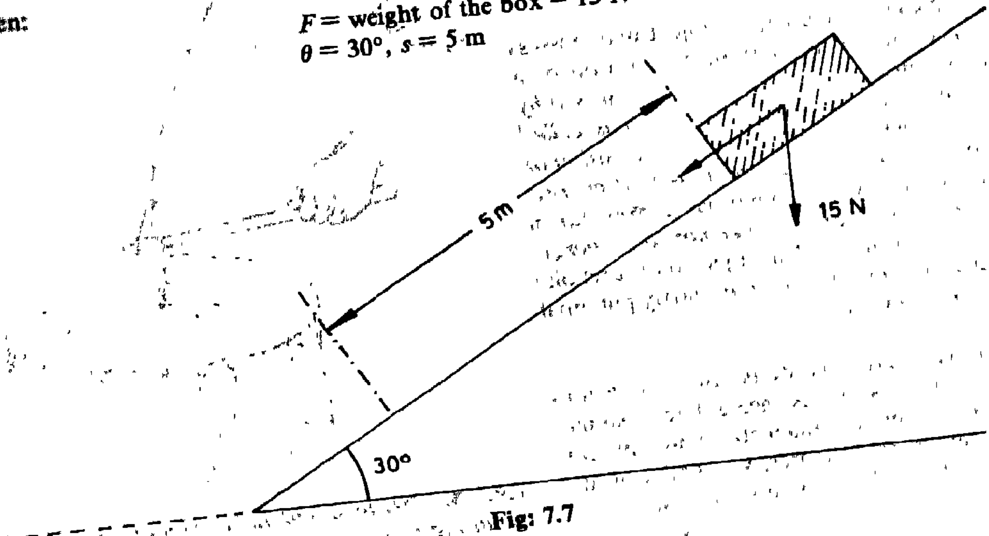


Fig: 7.7

The weight of the box will act vertically downwards (Fig. 7.7). The force required to pull the box will be equal to the component of the weight along the inclined plane, i.e., $F \sin \theta$. Hence, the work done

$$W = (F \sin \theta)(s) = (15\ \text{N} \times \tfrac{1}{2})(5\ \text{m}) = 37.5\ \text{J}$$
$$(\text{since } \sin 30^\circ = \tfrac{1}{2}).$$

7.4 Energy

'Energy' is another example of those words which are often used in everyday conversation but have a precise meaning for the physicist. We have seen that when work is done on any object by applying a force, it either gains in speed or undergoes a change in its position or shape. We know that a moving object can set another object in motion. For example, a moving ball on hitting another ball can set it rolling. Children play with glass marbles. They set a stationary marble moving by hitting it with another marble. Similarly, an object raised to a certain height by applying some force acquires the capability to do work. For instance, when a raised hammer is allowed to fall on a nail, it drives the nail into the wood (Fig. 7.8). A wound spring is used to work clocks and toys. Whenever we want some work done we need an agent, say a raised hammer, a wound spring, etc., which has the capability to do work. An object having capability to do work is said to possess *energy*. The total energy possessed by an object is measured in terms of its capacity to do work. Obviously, the unit of energy is the same as that of work, i.e., joule. We also note that energy, like work, is a scalar quantity.

As we have seen, an object may possess energy due to its motion, its position or a change in its shape. *The energy possessed by an object by virtue of its motion is called kinetic energy and that due to its position or change of shape is called potential energy.* Kinetic energy and potential energy taken together are called *mechanical energy*. Mechanical energy of an object may be wholly kinetic or wholly potential or partly potential and partly kinetic.

Energy also manifests itself in various other forms such as heat, light, sound, chemical, electric, magnetic and nuclear. However, in this chapter, we shall consider only mechanical energy in some detail.

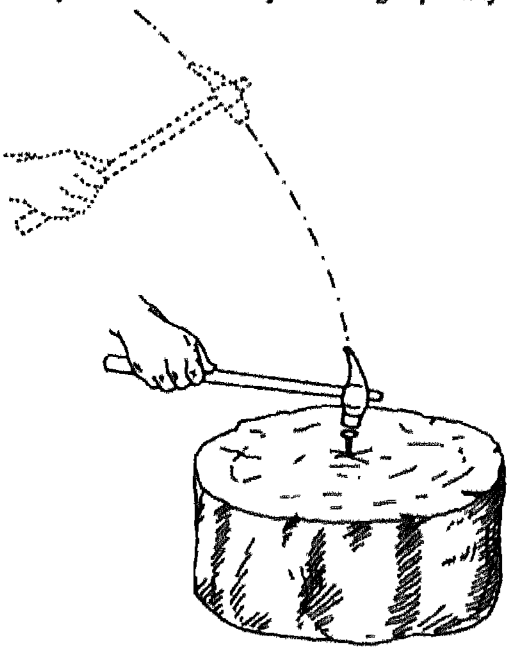


Fig. 7.8: *Driving a nail inside a block of wood by hitting it with a hammer.*

7.5 Kinetic Energy

Kinetic energy possessed by an object due to its motion is given by the amount of work that can be done by the object before coming to rest. It is also given by the amount of work done by the force on the object to bring it to its present state of motion, starting from rest.

Consider a body of mass, m, at rest. Suppose a force, F, is applied to it which moves it through a distance s. The body gets an acceleration, a, which is given by

$$a = F/m \tag{7.3}$$

Suppose it attains a velocity v after having travelled the distance s The work done on the body by the force that accelerates it appears as its kinetic energy, T

$$\begin{aligned} T &= \text{Work done} \\ &= Fs = m\,a\,s \end{aligned} \tag{7.4}$$

We also know from Chapter 4 equation (4.10) that

$$2\,as = v^2 - u^2 \tag{7.5}$$

Here $u = 0$

Hence $$T = \frac{mv^2}{2} = \tfrac{1}{2}\,mv^2 \tag{7.6}$$

This is the expression for the kinetic energy of an object of mass, m, moving with a velocity v It will be noted that kinetic energy is directly proportional to the mass of the object and to the square of its speed. If mass of the object is doubled, its kinetic energy will also be doubled, provided its velocity remains the same. On the other hand, if the velocity of the object is doubled, its kinetic energy will become four times.

Example 2: Find the kinetic energy of a ball weighing 0.2 kg and moving with a speed of 30.0 m/s.

We are given

$$\begin{aligned} m &= 0.2 \text{ kg} \\ v &= 30 \text{ m/s} \end{aligned}$$

Therefore,

$$\begin{aligned} \text{kinetic energy } T &= \tfrac{1}{2}\,mv^2 \\ &= \tfrac{1}{2}(0.2 \text{ kg})\,(30.0)^2\,(\text{m/s})^2 = 90 \text{ J} \end{aligned}$$

So, kinetic energy of the moving ball is 90 J.

Example 3: Find the speed of a ball of mass 100 g which possesses kinetic energy of 20.0 J.

We are given

$$m = 0.1 \text{ kg}$$
$$T = 20.0 \text{ J}.$$

We know that

$$T = \tfrac{1}{2} mv^2$$

or $$v^2 = \frac{2T}{m} = \frac{2 \times 20.0\text{J}}{0.1 \text{ kg}} = 400.0 \text{ (m/s)}^2$$

or $$v = 20.0 \text{ m/s}.$$

So, speed of the ball is 20.0 m/s.

7.6 Potential Energy

Potential energy of a body is either due to its position or due to a change in its shape. A force has to be applied to overcome the force of gravity if an object is to be raised to a certain height. The work done in this process gets stored in the object in the form of potential energy. This potential energy is measured with reference to the initial position of the object. Usually the ground level is considered as reference. But any other surface can be taken as reference level. For example, consider an object placed on a table of height h. If earth's surface is taken as reference, its potential energy will be equal to the work done in lifting the object from the ground level to the table top. On the other hand, if the top of the table is taken as the reference level, then the potential energy of the object lying on the table will be zero. Further, if the object is now raised through a height, h_1, above the surface of the table, its potential energy with respect to the earth's surface will be the work done in raising it through a height $(h+h_1)$. On the other hand, with respect to the table top the potential energy will only be the work done in raising it through a height h_1 (Fig. 7.9). If instead of gravitational force, the work is done against electric or magnetic forces, it also gets stored in the object in the form of potential energy.

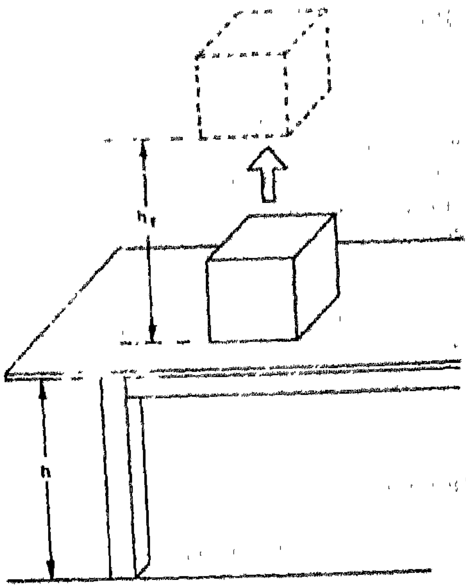


Fig. 7.9: *Raising an object by height h_1 from above the top of a table.*

Potential energy possessed by an object by virtue of its position can be calculated by determining the work done, W, in bringing the object to that position Suppose an object of mass m is raised through a height h above the earth's surface. The work done in the process will be given by equation (7.7)

$$W = mg \times h = mgh, \tag{7.7}$$

where g is the acceleration due to gravity. This work will get stored in the object as its potential energy. In other words, the potential energy of the object of mass, m, at a height, h, above the ground level will be mgh. We call this the gravitational potential energy to distinguish it from other forms of potential energy.

Example 4: Calculate the gravitational potential energy of a bucket of water of mass 5 kg when it is carried up one floor, at a height of 4 m.

Given $m = 5$ kg, $h = 4$ m, and $g = 10\ \text{m/s}^2$

As, potential energy $= mgh$

$= 5\text{kg} \times 10\ \text{m/s}^2 \times 4\ \text{m} = 200$ J.

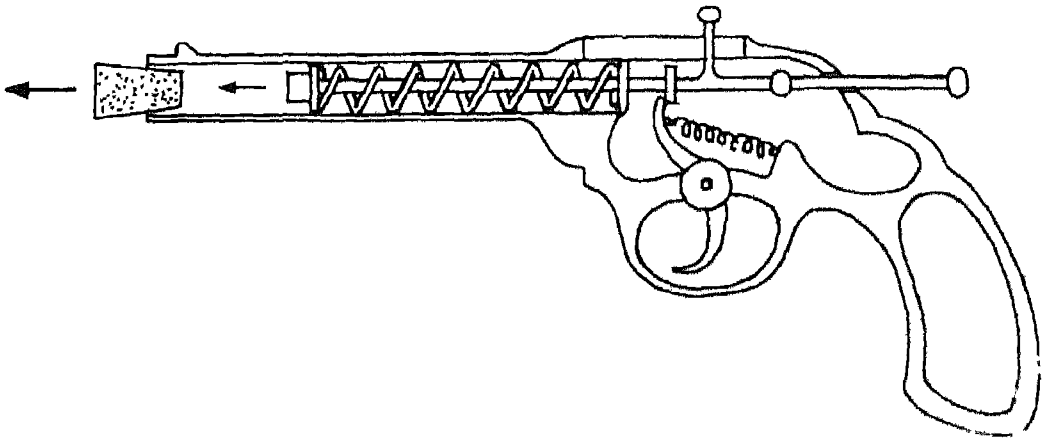
Therefore, potential energy of the bucket of water when raised by 4 m would be 200 J.

Work has also to be done to change the shape of an object. A change in shape may be brought about by compressing the object or by stretching it or by bending or twisting it. For example, a spring may be compressed or stretched. A rubber balloon filled with air can be compressed between two hands. If the force applied is not too large, the object will regain its original shape when the force is removed. (We will not consider those cases in which the applied force changes the shape of the object permanently, e.g., bursts the balloon or breaks the spring.) In such cases, the work done in the process of changing the shape of the object is stored in the form of potential energy which can be recovered in some other form. For example, in a toy pistol when the compressed spring is released by the trigger, the cork is thrown out (Fig. 7.10-a). Similarly, the potential energy of the stretched rubber band in a catapult is used to throw a stone over a considerable distance (Fig. 7.10-b)

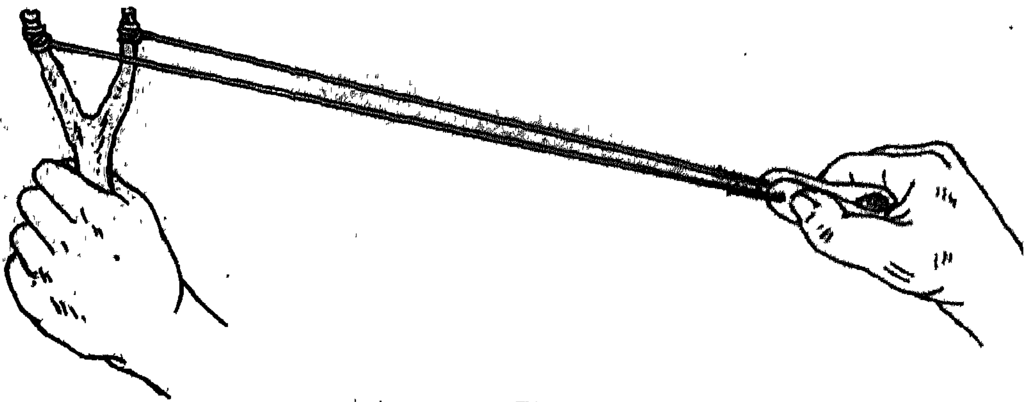
7.7 Power

In everyday life, we often find that the same work can be done by employing different means. For example, a labourer may take a few hours to carry a pile of bricks from the ground to the top of a building under construction. If a crane is employed, the same job can be accomplished in a few minutes. Thus, we find that the time taken to do equal amounts of work may be widely different in different situations. In order to compare the work done by different types of machines, it is useful to determine the work done in a unit time. ***The work done per unit time or the rate of doing work is defined as power and denoted by P.*** If the time required to do W amount of work be t, then power, P, is defined as

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}} \quad \text{or} \quad P = \frac{W}{t} \tag{7,8}$$



(a)



(b)

Fig. 7.10: *(a) A toy pistol (b) A catapult.*

When work is measured in joule and time in second, power is expressed in watt. Thus

$$1 \text{ watt (W)} = \frac{1 \text{ joule (J)}}{1 \text{ second (s)}} \quad \text{or } W = \frac{J}{s}$$

Power is sometimes expressed in kilowatt which is 1000 times one watt, i.e.

$$1 \text{ kilowatt (kW)} = 1000 \text{ watt (W)}$$

The capacity of machines to do work is expressed in terms of watt or kilowatt.

Example 5: Calculate the power of a pump which can lift 250 kg of water to a water tank at a height 30 m in 10 seconds.

In lifting water to the tank the pump has to work against the force of gravity So,

$$\text{work done } (W) = mgh$$

Here $m = 250$ kg, $h = 30$m and let us take $g = 10$ m/s^2.
Hence

$$W = 250 \text{ kg} \times 10 \text{ m/s}^2 \times 30 \text{ m} = 75000 \text{ J}$$

Now this work is done in 10 s, so power P of the pump

$$P = \frac{\text{Work done}}{\text{Time taken}}$$

$$= \frac{75000 \text{ J}}{10 \text{ s}}$$

$$= 7500 \text{ watt}$$

$$= 7.5 \text{ kilowatt.}$$

The power of the pump, therefore, is 7.5 kW.

7.8 Transformation of Energy

One of the important characteristics of energy is that it can be transformed from one form to another. We know that a stone released from a height immediately starts moving towards the ground. The initial potential energy of the stone gradually gets transformed into kinetic energy and by the time it reaches the ground its entire energy will be in the form of kinetic energy. Similarly, when a ball is thrown upwards its initial kinetic energy changes into potential energy as the ball moves up. At the highest point of its path the speed of the ball will be zero and so will be its kinetic energy. At this stage its total energy will be in the form of potential energy. Again, when the ball starts falling down, its potential energy changes into kinetic energy just as that of a freely falling stone.

7.9 Law of Conservation of Energy

Transformation of energy from one form to another does not result in gain or loss of energy. In other words, the total energy before and after transformation remains unchanged. This is known as the law of *conservation of energy*. The law may also be stated as: '*energy can neither be created nor destroyed but can be transformed from one form to another*'.

Note that what we have stated here implies a very important assumption that the different forms of energy can be measured in very precise terms, for otherwise the law of conservation will have no meaning.

Total energy of the system remains conserved in all natural processes. However, during transformation of energy from one form to another a part of the energy may get converted into undesirable forms. For example, in any machine a fraction of the energy goes into overcoming friction between its moving parts and this appears in the form of heat. Even in the case of a freely falling body, a small fraction of energy goes into overcoming the resistance of air. This fraction of energy is absorbed by the atmosphere in the form of heat. The law of conservation of energy requires that the energy lost through heating be also taken into account.

So far we have only learnt to measure kinetic energy and gravitational potential energy. We consider an example involving only these two forms of energy.

Example 6: Deduce the equation $v^2 = u^2 + 2gs$ by applying the principle of conservation of energy in the case of a freely falling object.

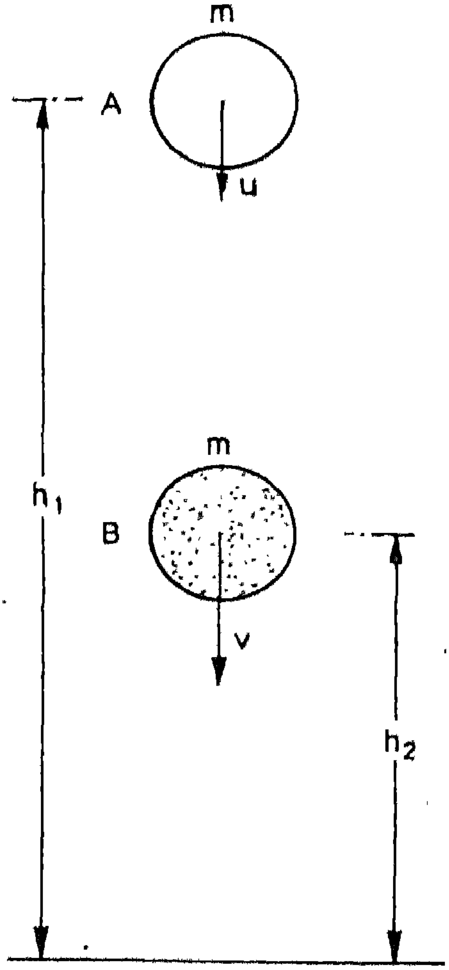


Fig. 7.11: *A freely falling body.*

Let the velocities of a freely falling object at points A and B be u and v, respectively (Fig. 7.11). Let the height of point A be h_1 and that of point B be h_2 from the ground. If m be the mass of the object then,

Kinetic energy at point A = $\frac{1}{2} mu^2$

and Kinetic energy at point B = $\frac{1}{2} mv^2$

Similarly, the potential energy of the object at points A and B will be mgh_1 and mgh_2 respectively.

Now, the total energy of the object at any point will be equal to the sum of its potential and kinetic energies. (We assume that no energy is lost due to friction of air.)
Therefore,

Total energy at point A= $\frac{1}{2} mu^2 + mgh_1$

and Total energy at point B= $\frac{1}{2} mv^2 + mgh_2$

According to the principle of conservation of energy, the total energy at point A should be equal to that at point B.

Hence,

$$\frac{1}{2} mu^2 + mgh_1 = \frac{1}{2} mv^2 + mgh_2$$

or $$\frac{1}{2} m (v^2 - u^2) = mg (h_1 - h_2)$$

or $$v^2 - u^2 = 2g (h_1 - h_2)$$

Let $(h_1 - h_2) = s$, then we finally obtain $v^2 = u^2 + 2gs$ which is the desired equation of motion.

ACTIVITIES

1. Run up a flight of stairs and time it. Knowing your mass and the height of each step, find the work done and the power.
2. Do the exercise of "sit-ups" (sit and stand alternately as fast as you can) for as long as you can. Measure the time. Find your weight Assuming that in standing up you lift your body weight by an amount equal to the difference in the level of the head between standing and sitting, find the work done and the power.

QUESTIONS AND PROBLEMS

1. A man of mass 50 kg jumps a height of 1.2 m. What is his potential energy at the highest point?

   [Ans. 600 J]
2. How fast should a man of mass 50 kg run, so that his kinetic energy is 625 J?

   [Ans. 5 m/s]
3. What is the kinetic energy of a ball of mass 0.1 kg when it is thrown with a speed of 15 m/s?

   [Ans. 11.25 J]
4. Calculate the work done when a mass of
   (a) 5 kg is lifted 8m,
   (b) 200 g is lifted 5 cm.

   [Ans. (a) 400 J; (b) 0.1 J]

5. Calculate the work done in taking a packet of mass 10.0 kg to the top of a building of height 14.0 m.

[**Ans.** 1,400 J]

6. The mass of a car is 1200 kg. Calculate its kinetic energy when it is moving with a speed of 80 km/h.

[**Ans.** $T \simeq 3 \times 10^5$ J]

7. State the law of conservation of energy and explain its consequences.
8. Explain the terms '*joule*' and '*watt*'.
9. A man of mass 60 kg runs up a flight of 30 steps in 40 seconds. If each step is 20 cm high, calculate his power.

[**Ans.** 90 W]

10. A block of 20 kg mass is pulled up a slope by applying a force acting parallel to the slope. If the slope makes an angle of 30° with the horizontal, calculate the work done in pulling the load up a distance of 3 m. What is the increase in potential energy of the block?

[**Ans.** 300 J]

CHAPTER 8

Heat

IN THE EARLIER chapters, we learnt about mass, motion, force, energy, etc. These are all related concepts and constitute the study of a branch of physics which is known as Mechanics. We now turn to another major branch of physics, called Heat. We first consider some of the important concepts in this field and will then describe some physical effects of heat.

8.1 Hot and Cold are Relative

From a very early age we become familiar with the sensations of hot and cold. A pot taken off the fire is hot and so is the open ground on a summer afternoon. On the other hand, water from an earthen pot is cold and so is ice or ice-cream. But you must realize that these sensations are relative and you can very easily verify this.

Take three mugs. In one, fill luke-warm water, in another cold water (a little ice may be added if available) and in the third, hot water (as hot as your hands can stand). Put one hand in the mug with hot water and the other in the mug with cold water. Let them be there for about a minute or more. Now take them out and put both hands immediately into the mug with luke-warm water. You will find that your hand which was in the mug with the hot water now feels the water as cold, whereas the hand which was earlier in the cold water feels the same water to be warm. This shows that the feeling of the hot and cold is relative.

Let us take another activity. On a sunny afternoon, place outside in the sun a metal object like a tumbler or a 'katori' or a pan, and a non-metallic object like a book or a piece of cloth or a wooden object like a small stool or a rolling pin. Leave them out for about half an hour. Now

you go and touch them one after the other. You will feel the metal object is much hotter than the non-metallic one. This shows that the sensation of hotness is not only relative but it also depends upon the nature of the body we touch.

8.2 Temperature

We can use our sense of touch in a very limited range of cold and hot. We, therefore, need a device which is independent of our sense of touch and which will measure the hotness of a body. Such a device is called a thermometer. The first thermometer was developed by Galileo (1564–1642) in the sixteenth century. He noticed that gases expand on heating; he used this property of gases to build a thermometer. One can repeat his experiment because it is so simple.

Take a round bottom flask (of about 1 litre capacity) and fix a long (about 50 cm) glass tube to it through an air-tight cork. Warm the flask by placing it in the sun for some time (say half an hour). Bring it in and immediately fix it on a stand in an inverted position with the lower end of the glass tube dipped well inside a beaker filled with coloured water (Fig. 8.1). As the flask cools, water rises inside the tube and after some time attains a steady height. If you now cool the flask by pouring cold water over it or by keeping a wet cloth over it, the water level in the tube will rise further. If you heat the flask even slightly by bringing a candle flame near it, the water level in the tube will fall. The change in the level of water in the tube thus indicates the change in temperature. In this particular experiment, when the level falls, we say that the temperature of the air in the flask has increased and when it rises, it indicates a drop in the temperature. Temperature thus expresses the degree of hotness (or coolness) possessed by a body.

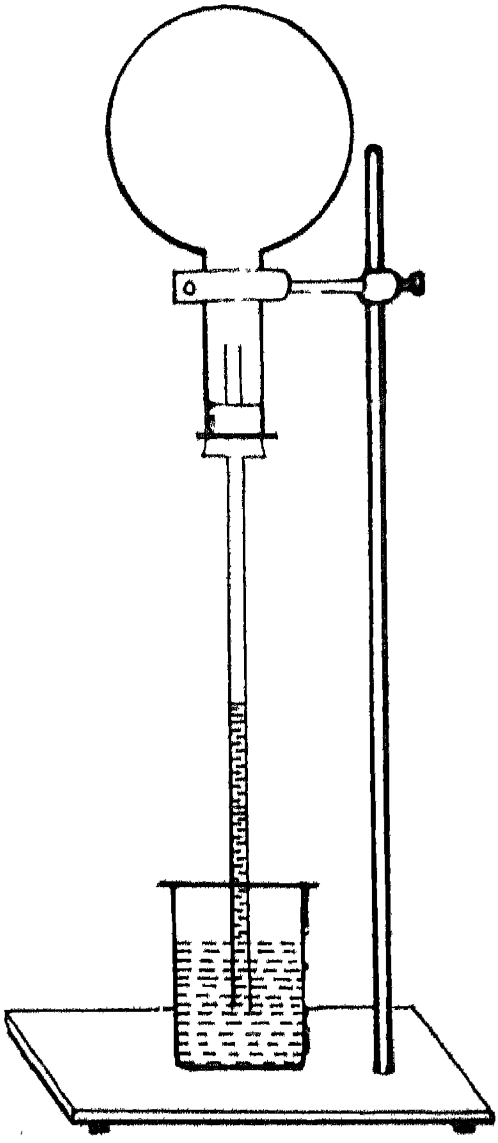


Fig. 8.1: *Model of an air thermometer.*

8.3 Heat and Thermal Equilibrium

You would have observed that if boiled milk or cooked vegetables are left on a table or at any other place away from fire, they begin to cool gradually. This process goes on till they attain the same temperature as that of the surroundings. On the other hand, if you take some pieces of ice in a small container or some ice-cream in a cup and leave it undisturbed, it will gradually melt and the liquid so formed will gradually warm up to reach the temperature of the surroundings.

We also know that when we dip a hot object like an iron nail in cold water, soon the nail becomes cold Thus, it is clear that when two bodies at different temperatures come in contact with each other (in the earlier examples the vessel containing milk is in contact with the surrounding air), the hotter body becomes cooler and the colder becomes warmer till they attain the same temperature. Obviously, something is exchanged between a hot and a cold body during the time they are in contact and their temperature is changing that which has been transferred is called *heat*. We say that the body at higher temperature has lost some heat while that at lower temperature has gained some heat No heat flows when the two bodies are at the same temperature. The state when no heat flows from one body to another is known as the state of *thermal equilibrium*. In other words, *temperature of a body is a property which governs the flow of heat*. When two bodies in contact have the same temperature, no heat will flow between them and they are said to be in thermal equilibrium. Heat will always flow from a body at a higher temperature to the one at a lower temperature.

The most commonly used thermometer is a sealed capillary tube containing a liquid (usually mercury) which expands as its temperature increases. To measure the temperature of a body, such a device is brought in contact with the body and sufficient time is allowed for them to reach a state of thermal equilibrium. Under this condition, the length of the liquid column in the capillary stops changing, indicating that the body and the device have reached thermal equilibrium. To express temperature numerically, we calibrate the thermometer in the following way.

We choose two fixed temperatures which are called the fixed points. In the celsius scale, named after Celsius (1701-1744), the temperature at which pure ice melts at normal atmospheric pressure is taken to be zero degree (0° C) and the temperature at which pure water boils (under normal atmospheric pressure) is taken to be 100° C. The separation between these

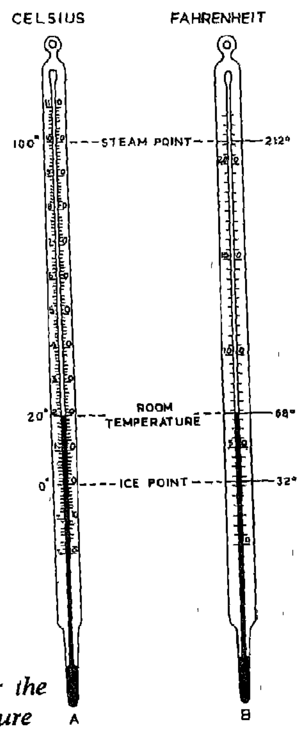


Fig. 8.2: *Two thermometers A and B calibrated for the celsius scale (A) and fahrenheit scale (B) of tempertaure*

two fixed points is divided into 100 equal divisions. Each such division measures a temperature difference of 1°C (degree celsius). On the fahrenheit scale named after Fahrenheit (1686-1736), these fixed points are defined as 32°F and 212°F respectively and the separation between them is divided into 180 divisions. Fig. 8.2 shows two such thermometers calibrated on the celsius and fahrenheit temperature scales.

8.4 Heat from Energy of Motion

In an earlier chapter you learnt that frictional force acts between a moving body and the surface on which it moves (or between the body and the medium through which it moves). Due to friction, a part of the kinetic energy of the body is converted into heat. For instance when you rub your hands, you soon begin to feel the hands getting warmer. You might also have noticed that when two stones strike against each other, sparks are often produced. When riding a fast moving bicycle you suddenly apply brakes, the rim of the wheel will get hot. You can check this. A meteorite, entering the earth's atmosphere, gets red hot due to friction with air and is completely vaporised before reaching the surface of the earth. The above examples clearly illustrate that the kinetic energy of a body lost due to friction appears in another form of energy, which we call heat or *thermal energy*.

8.5 Unit of Heat

What are the factors on which the quantity of heat required to warm a substance depends? Take some water in a vessel and heat it through a temperature rise of say 5° C (for instance from 30° C to 35° C) and note the time taken. Now, to raise the temperature of the same amount of water by 10° C, using the same source of heat, will require twice the time and hence double the quantity of heat. In another experiment, suppose you now take double the amount of water but heat it using the same heating arrangement through the same rise of temperature (5° C). You will again find that the time taken is twice that required in the first part of the experiment.

In general, it has been found that the quantity of heat required to heat a substance depends upon its mass and the rise in temperature. To heat 1 g of a substance through 1° C, we always require some definite quantity of heat. This is called the *specific heat* of the substance. This amount of heat in the case of water is called a *calorie* (abbreviated as cal) and is one of the units of heat.* According to this, the unit of specific heat is cal per g per °C (cal/g°C). A kilocalorie (k cal) is the quantity of heat required to raise the temperature of 1 kg of water through 1° C.

8.6 Mechanical Equivalent of Heat

We have observed above that the energy used against the force of friction appears in the form of heat. This observation by itself is not enough to show that energy is being conserved; we must, in addition, know how much heat is produced when a given amount of energy is spent. James Joule (1818-1889) was the first to demonstrate that the ratio between the energy lost in a mechanical process and the heat produced in the process is a constant. It is found that whatever be the nature of the substance or its volume, 4185 joule of mechanical work will always produce

*More precisely, calorie is defined as the amount of heat required to raise the temperature of 1 g of water from 14.5° C to 15.5° C.

1 k cal of heat. The ratio $\frac{4185 \text{ joule}}{1 \text{ k cal}}$ is known as the mechanical equivalent of heat and it is represented by the symbol J. In other words, we may write 1 k cal = 4185 joule

or $$1 \text{ cal} \simeq 4.2 \text{ joule}$$

All forms of energy, including heat, are now measured in joule. In terms of joule the unit of specific heat is taken as joule per kilogram degree celsius (or J/kg° C). Thus, the specific heat of a substance is defined as the quantity of heat (in joule) required to raise the temperature of 1 kg of the substance through 1° C. Specific heat of a substance is usually represented by the symbol C. Values of specific heat for a few substances are given in Table 8.1.

TABLE 8.1: **Specific Heat, C, of Some Substances around 20° C**

Mercury	0.13×10^3 J/kg° C
Water	4.18×10^3 J/kg° C
Brass	0.38×10^3 J/kg° C
Copper	0.39×10^3 J/kg° C
Gold	0.17×10^3 J/kg°C
Silver	0.23×10^3 J/kg° C
Iron	0.48×10^3 J/kg° C
Glass (Flint)	0.50×10^3 J/kg° C
Marble	0.90×10^3 J/kg° C

According to the above, the heat Q required to raise the temperature of m kg of a substance of specific heat C through T° C would be

$$Q = m\ CT \tag{8.1}$$

We often want to know the amount of heat required to raise the temperature of a body by a certain amount. For this it is convenient to define a quantity called the *thermal capacity* of the body. It is the heat required to raise the temperature of the body by 1°C. It is equal to the product of its mass and the specific heat of its material. For example, the thermal capacity of a copper vessel of mass m would be $m\ C$, where C is the specific heat of copper.

8.7 Equilibrium Temperature

Consider two bodies A and B, A at temperature T_A and B at temperature T_B, with $T_A > T_B$. We have learnt that if these bodies are brought in contact, then heat will flow from the body at temperature T_A to the one at temperature T_B. In this process, the temperature of body A will fall and that of body B will rise. This will continue till the temperature of both the bodies becomes equal. When this happens, we say that the two bodies have reached thermal equilibrium.

One can easily predict the equilibrium temperature from the law of conservation of energy. Let us suppose that the mass of body A is m_A and its specific heat is C_A. Similarly let the specific heat of body B be C_B and let its mass be m_B. Suppose the equilibrium temperature is T_e, then the

energy lost by body A in cooling down from T_A to T_e is

$$C_A\ m_A\ (T_A - T_e).$$

This must be equal to the energy gained by body B in getting heated from temperature T_B to T_e ($T_B < T_e$) which will be given by

$$C_B\ m_B\ (T_e - T_B)$$

Therefore, we must have

$$C_A\ m_A\ (T_A - T_e) = C_B\ m_B\ (T_e - T_B) \tag{8.2}$$

Transferring terms with T_e on one side we obtain

$$T_e = \frac{C_A\ m_A\ T_A + C_B\ m_B\ T_B}{C_A\ m_A + C_B\ m_B} \tag{8.3}$$

Equation (8.2) can be used to determine the specific heat of a body.

Example 1: We pour 2 litres of water at 80° C in a plastic bucket containing 10 litres of water at 20° C. What is the final temperature of water? (In your calculations, ignore the heat taken by the bucket.)

The final temperature of water will be given by the equation (8.3)

i.e.,
$$T_e = \frac{C_A\ m_A\ T_A + C_B\ m_B\ T_B}{C_A\ m_A + C_B\ m_B}$$

Since we are mixing water with water, here $C_A = C_B$. Further, $m_A = \rho\ V_A$ and $m_B = \rho\ V_B$ where ρ is the density of water (assumed to be independent of temperature). We, therefore, have

$$T_e = \frac{V_A\ T_A + V_B\ T_B}{V_A + V_B}.$$

In the given problem

$$V_A = 2 \text{ litres},\ T_A = 80°\,\text{C, and } V_B = 10 \text{ litres},\ T_B = 20°\,\text{C}$$

hence,

$$T_e = \frac{(2 \text{ litres})\ 80°\text{C} + (10 \text{ litres})\ 20°\text{C}}{2 \text{ litres} + 10 \text{ litres}} = \frac{360 \text{ litres} \times °\text{C}}{12 \text{ litres}} = 30°\,\text{C}$$

Thus the final temperature of water would be 30° C.

Example 2: A cube of copper weighing 0.1 kg is placed for sufficient time in a vessel containing boiling water. The temperature of the cube then is 100° C. It is taken out and immediately transferred to another metallic vessel containing 0.25 kg of water at 20° C. The temperature of water rises and attains a steady value of 23° C. What is the specific heat of copper? Given: the specific heat of water is 4.2×10^3 J/kg° C. (In the calculations, ignore the heat taken by the metal vessel into which the copper block is dropped.)
Specific heat of copper C_A can be found by using the equation 8.2. It will be given by

$$C_A = \frac{C_B \; m_B \; (T_c - T_B)}{m_A \; (T_A - T_c)} \tag{8.4}$$

We note that

C_B = specific heat of water = 4.2×10^3 J/kg°C
m_B = mass of water = 0.25 kg
$T_c - T_B = (23-20)°\ C = 3°\ C$;
m_A = mass of copper cube = 0.1 kg;
$(T_A - T_c) = 77°\ C$

$$C_A = \frac{4.2 \times 10^3 J}{kg°\ C} \times \frac{0.25\ kg}{0.1\ kg} \times \frac{3°\ C}{77°\ C} = 0.409 \times 10^3 J/kg°\ C$$

Thus the specific heat of the copper is 0.409×10^3 J/kg° C

8.8 Effects of Heating

8.8.1 Expansion of Solids. We will now consider a few effects of heat on bodies. We have already noted that all substances (leaving out a few exceptions) whether solid, liquid or gas expand on heating.

Let us discuss a few familiar examples to illustrate expansion of solids. In the construction of long metal structures, the effect of heating has to be taken into account. While travelling by train, you would have heard thuds at regular intervals. These arise because there is a small space between two rails where they are joined (Fig. 8.3-a). Each rail is 13 m in length. The space between two rails is left to allow for expansion of the rails during summer. These days, in some countries and also partly in India, the railways are using welded rails with single rail length of a few kilometres. Two such rails are joined in a wedge, so that when rails expand, they slide

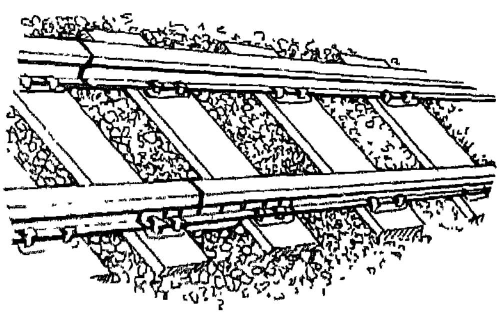
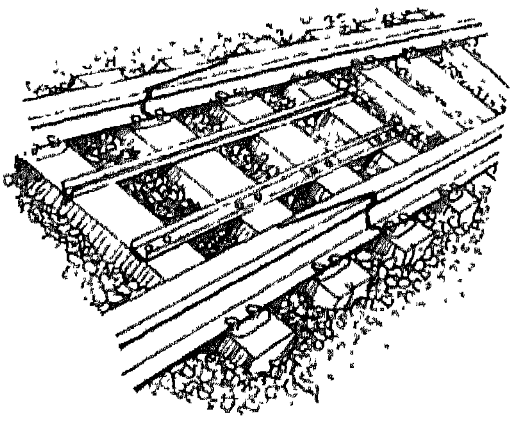


Fig. 8.3.-a, b: *Arrangements of joining two rails of single lengths.*

past each other (Fig 8 3-b). In metal pipes used for carrying oil or any other liquid over long distances, loops are usually provided at regular intervals (Fig. 8.4-a, b). This is to avoid the strain that would otherwise develop in the pipe due to changes in the atmospheric temperature. Blacksmiths use this effect with great advantage to fix a metal rim on a wooden wheel of a bullock cart. They make the metal rim a little smaller in diameter than the wheel. They heat the rim so that it expands and fits on the wheel. It is cooled by pouring water over it so that it contracts and fits the wheel tightly.



8.3-b

Pendulum clocks usually lose time during summer and gain time during winter. This is because of the change in the length of the pendulum with temperature.

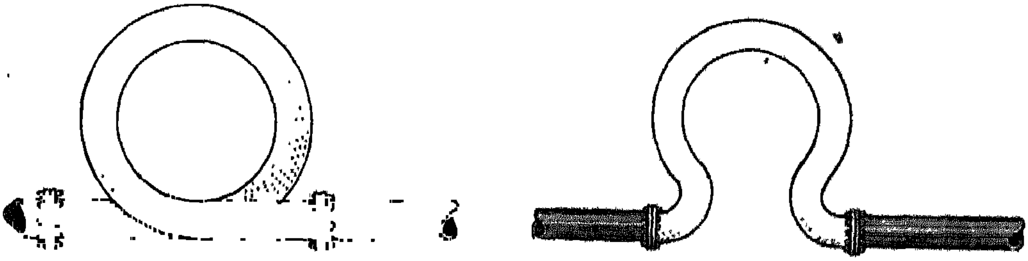
Consider a metal rod at temperature T_1. Let us measure the length and denote it by l_1. We heat the rod slightly and uniformly, so that now it is at temperature T_2. Let the new length of the rod be l_2. Then it has been experimentally observed that in most cases and for not too large difference in temperatures $(T_2 - T_1)$, we have

$$(l_2 - l_1) \propto (T_2 - T_1)$$

Also the change in length $(l_2 - l_1)$ is proportional to the original length l_1 (i.e., a rod of length 2 m will expand twice as much as a rod of length 1 m). Hence combining these two experimental facts, we write

$$(l_2 - l_1) = \alpha\, l_1\, (T_2 - T_1) \tag{8.5}$$

$$\text{or } l_2 = l_1 \left\{ 1 + \alpha\, (T_2 - T_1) \right\} \tag{8.6}$$



(a) (b)

Fig. 8.4-a, b: *Two designs of loops provided in long metal pipes used for carrying fluids.*

where α (Greek letter 'alpha') is a constant characteristic of the material and is called the *coefficient of linear expansion* of the material of the rod. Values of α for a few solids are given in Table 8.2.

If we consider a rectangular block of a solid, then all its sides will expand on heating according to the above formula resulting in an increase in its volume.

TABLE 8.2: **Coefficient of Linear Expansion of Some Solids**

Gold	14×10^{-6} per °C
Iron	12×10^{-6} per °C
Silver	19×10^{-6} per °C
Steel	11×10^{-6} per °C
Soft Glass	8.5×10^{-6} per °C
Pyrex Glass	3×10^{-6} per °C
Copper	17×10^{-6} per °C

One of the practical applications of thermal expansion of metals is in bimetallic strips which are most commonly used as reliable thermoswitches in automatic electric irons, refrigerators, temperature-controlled ovens, toasters, etc. Two metal strips whose thermal coefficients of linear expansion are different are riveted together. As the temperature changes, the change in length of each strip will be different. As a result the strip bends. The amount of bending depends on the rise in temperature. In the bimetallic strip shown in the Fig 8.5-a, the expansion coefficient of metal 1 is larger than that of metal 2. Thus when such a bimetallic strip is used in an automatic electric iron, the bending due to thermal expansion (Fig. 8.5-b) helps in breaking the circuit and controls the temperature of the iron while in use.

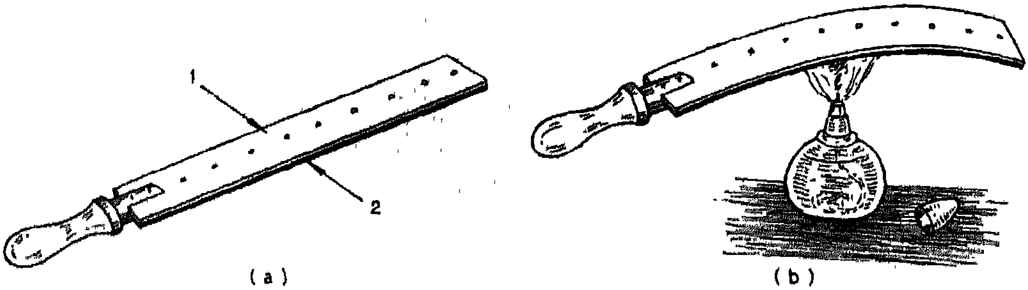


Fig. 8.5: *Side view of a bimetallic strip made of a pair of metals 1 and 2; (a) shows the strip at room temperature and (b) shows it bent on heating.*

Example 3: Calculate the change in length of an iron rail of length 13 m when its temperature changes from 5°C to 45°C.

$$\begin{aligned}(l_2 - l_1) &= \alpha l_1 \ (T_2 - T_1)\\ &= 12 \times 10^{-6}/^\circ C \times 13 m \times 40^\circ C\\ &= 6.24 \times 10^{-3} m\\ &= 6.24 mm.\end{aligned}$$

So, the resulting change in length of the rail would be 6.24 mm.

8.8.2 *Expansion of Liquids.* For the same rise in temperature, liquids expand more than solids. If V_1 is the volume of a given mass of a liquid at temperature T_1 and if V_2 is its volume at temperature T_2,

We have $(V_2 - V_1) \propto V_1$

and also $(V_2 - V_1) \propto (T_2 - T_1)$

Hence we may write

$$(V_2 - V_1) = \gamma \ V_1 \ (T_2 - T_1)$$

Where the constant γ (Greek letter 'gamma') is called the *coefficient of cubical expansion* of the liquid. Thermal expansion of mercury is utilized in making thermometers. Values of γ for a few liquids are given in Table 8.3.

TABLE 8.3: **Coefficient of Cubical Expansion of Liquids, γ around 20° C**

Mercury	18×10^{-5} per° C
Water	21×10^{-5} per° C
Benzene	122×10^{-5} per° C

8.9 Change of State

We will now consider another effect of heating on substances. If we start with a solid and heat it to a sufficiently high temperature, it will melt, i.e., turn into a liquid (there are a few exceptions but we will not consider them here). If we continue heating the liquid it will vaporize, i.e., change into gas. Let us consider water and study these changes in some detail.

8.9.1 Latent Heat. Suppose we start with some ice in a beaker. Note the temperature of ice. It should be 0° C. We now start heating it on a constant but slow heat source as shown in Fig. 8.6. (A low voltage electric heater should be fine.) Note the temperature after every few minutes and make a plot of temperature and time (Fig. 8.7). First remarkable thing we notice is that the temperature does not rise although we are heating the ice. (We must continuously stir the mixture of water and ice so that the temperature is uniform throughout.) This condition prevails till there is any ice in the beaker. This observation seems to contradict what we learnt earlier, that the temperature of a body rises if heat is supplied to it. However, in the present case,

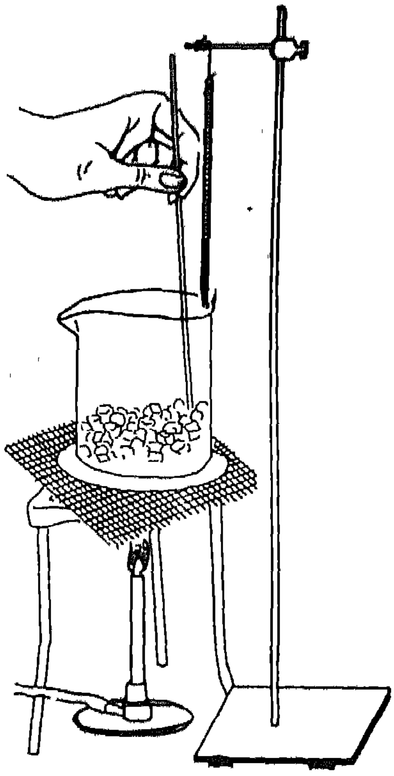


Fig. 8.6: *The set-up for an activity to study heating of ice and water.*

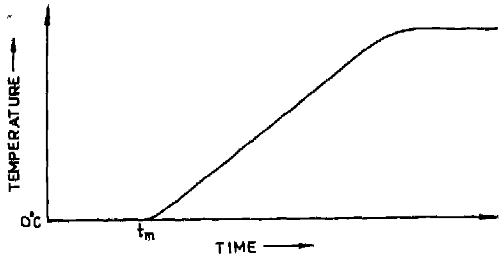


Fig. 8.7: *Time-temperature graph for the changes of state of ice on heating.*

the heat supplied to the system (i.e., ice and water), while ice is still melting is utilised in changing the solid (ice) into liquid (water). This happens without any change in the temperature of the system The quantity of heat required to completely change 1 kg of a solid to liquid at its melting point, without any change in temperature, is known as the *latent heat of melting.* Conversely, heat equivalent to the latent heat of melting is given out by the system when 1 kg of a liquid substance gets converted into solid at freezing point.

Let us again consider the graph shown in the Fig. 8.7. It will be seen that temperature begins to rise after some time, which we denote by t_m. It indicates that all ice has melted at time t_m. Beyond this time the temperature keeps rising till it reaches nearly 100°C, when it again becomes steady. It indicates that the water has started boiling. The heat supplied is now utilised to turn water from liquid state to vapour or gaseous state. The latent heat of vaporization is defined as the quantity of heat required to convert 1 kg of water at 100° C into water vapour at the same temperature. When water vapours condense to form liquid water, heat equivalent to latent heat of vaporization is given out.

Evaporation causes cooling, because when water evaporates it requires energy—the latent heat of vaporization. This heat is taken from the body in contact with water. If you wet the back of your hand (this part is more sensitive than the palm), you will feel that part getting cold. If you place your hand in a breeze or fan it, the feeling will be stronger, because by doing so you are increasing the rate of evaporation. You must have noticed that after a hot sunny day, particularly during summers, people sprinkle water on the roof or on open ground near their houses. The large latent heat of vaporization of water helps to cool the hot surface rapidly.

When it is very hot, we perspire and evaporation of perspiration helps to cool our bodies. This is nature's way of maintaining a steady body-temperature which for us is 37° C. During the summer months, trees acquire new leaves. Evaporation of water from the trees therefore greatly increases and it keeps them cool.

A *surahi* or an earthen pot has a large number of extremely small pores. Water seeps out through them and evaporates from the surface, cooling the whole system. The latent heat required for evaporation is taken from the water in the *surahi*. As a result, the water becomes cooler.

8.9 2 Relative Humidity. Water vapour are always present in the atmosphere and are invisible like other gases—oxygen, nitrogen or carbon dioxide. Their presence is very easily demonstrated. If you pour chilled water from a refrigerator or ice-cold water into a metal or glass tumbler, soon you will begin to see water condensing on the outside of the tumbler. This water, so to speak, is 'squeezed' out of the atmosphere. When you leave wet clothes in the sun, they soon dry. The water sticking to the fibres of the clothes gets vaporized and becomes part of the atmosphere. Similarly, a vast amount of water vaporizes from ponds, rivers and oceans besides the land mass, in general. Most of these vapour are always present in the air.

At any given temperature, air cannot hold more than a definite amount of water vapour. When air holds this maximum amount of water vapour, it is said to be saturated. Table 8.4 gives the mass in gram of water contained in one cubic metre of air saturated with water vapour (at 76 cm Hg of total pressure).

TABLE 8.4: **Mass of Water in One Cubic Metre of Saturated Air at Different Temperatures (at 760 mm Hg of Total Pressure)**

Temp. of water in °C	10°	15°	20°	25°	30°	35°	40°
Mass of water in 10^{-3} kg	9.3	12.7	17.1	22.8	30.0	39.2	51.0

Note that with increasing temperature air can hold more water. Thus if we have 1 m^3 of saturated air at, say, 40° C and we cool it rapidly to 30° C, almost 0.02 kg of water will condense out.

Air is rarely saturated. It contains much less water vapour than the maximum limit. Suppose at a given temperature a metre cube of air holds m kg of water vapour when it could hold m_s kg on saturation. The quantity $\frac{m}{m_s} \times 100$ is called the relative humidity. Normally, the value of relative humidity (RH) of a place on previous day is published in newspapers. If RH is high, we feel sultry; clothes do not dry easily. Temperatures between 22° C and 25° C with a RH value of about 50% are considered comfortable.

ACTIVITIES

1. Take a one-litre flask. Fill it to the brim with coloured water. Fix a long glass tube

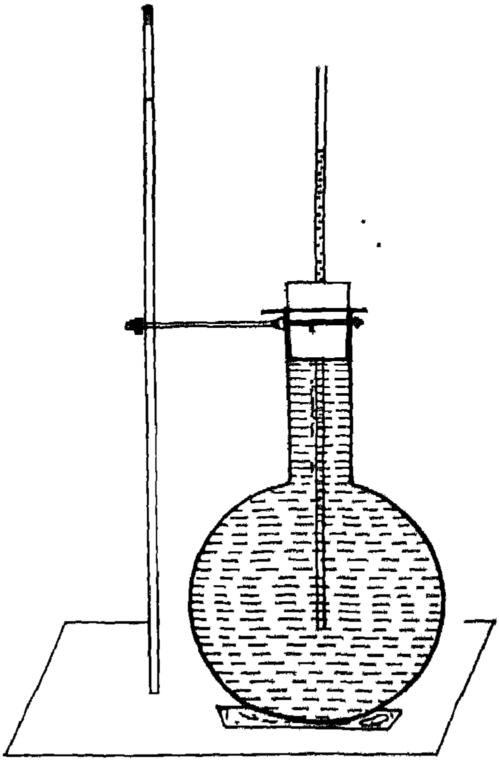


Fig. 8.8: *Set-up for an activity to observe the change in volume of water on heating and cooling.*

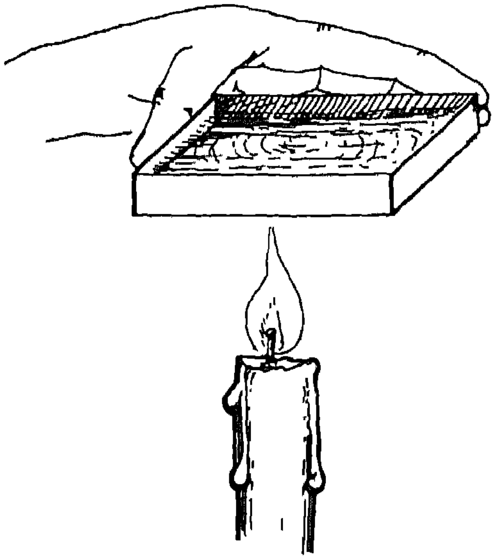


Fig. 8.9: *Set-up for an activity to heat water in a paper tray.*

to it through an air-tight cork. Some water will rise in the glass tube/(Fig. 8.8). Observe the rise and fall in the level of water in the tube with changes in temperature of water on heating and then on cooling the flask.

2. Take a cup or a mug and weigh it. Pour boiling water into it and stir it for some time. Note the temperature of water every half minute. When the temperature is steady, note the value. Weigh the cup again to find the mass of water added to the cup. Find the specific heat of the container. What are the sources of error in this experiment?
3. Set up dry and wet bulb thermometers and determine the relative humidity.
4. Take a used post-card or cut out a card about the size of 5 cm × 8 cm. Make a leak-proof tray out of it (Fig. 8.9). Pour some water into it. Hold it carefully over a candle flame so that you do not burn the edges. You should be able to heat water in this tray to a fairly high temperature (You may try this experiment even by using paper cup.) Why does the paper tray not burn?

QUESTIONS AND PROBLEMS

1. Consider two scales A and B shown in Fig. 8.2. Find the relation between readings on the two scales.

$$\left\{\begin{array}{r}\textbf{Ans } x^\circ F = [(x - 32)\, 5/9]^\circ C \text{ or} \\ x^\circ C = [(x \times 9/5) + 32]^\circ F\end{array}\right\}$$

2. Calculate the energy required to heat 1 kg of water from 20° C to 100° C.

[**Ans.** $Q \simeq 33 \times 10^5$ J]

3. Why is ice at 0° C more effective in cooling than water at 0° C?
4. Which produces more severe burns, boiling water or steam? Why?
5. When 500 g boiling water is poured into a mug which weighs 0.15 kg, the temperature of water falls to 70° C. If the specific heat of the subtance of the mug is 0.8×10^3 J/kg$^\circ$ C, calculate the amount of heat lost by water.

[**Ans.** Heat lost by water = 6.3×10^4 J]

6. When 0.2 kg of brass at 100° C is dropped into 0.5 kg of water at 20° C, the resulting temperature is 23° C. Find the specific heat of brass.

[**Ans.** C for brass is 0.41×10^3 J/kg$^\circ$ C]

7. Why does a glass tumbler made of soft glass crack when hot tea is poured into it, whereas a beaker made of pyrex glass does not?
(**Hint:** Examine the value of α for the two glasses).
8. A scale made of iron is exactly a metre in length at 20° C. What will be its length at 40° C?

[**Ans.** Length at 40° C, $(1 + 2.4 \times 10^{-4})$ m]

9. Why does one fill a hot-water bottle with hot water rather than with any other hot liquid?
10. Define the terms: (a) coefficient of linear expansion and (b) coefficient of cubical expansion.

PRACTICAL WORK

A WORD TO THE STUDENTS

Physics is an experimental science. Here we try to understand how things happen. Since generally all processes are quite complicated, it is not easy to understand any process all at once. Take a simple example of two bodies, a feather and a stone, falling together. You can easily verify that the stone falls towards the earth far more rapidly than the feather. This appears contrary to what we learnt in Chapter 6 on 'Forces in Nature'. There we established that acceleration due to gravity is independent of the mass of the falling body. Hence, to understand the results of the above experiment, we must consider the different factors affecting the fall of bodies. We have already talked about two such factors. (i) the gravitational force and (ii) the mass of the body. The third factor could be the air through which the bodies fall. To test whether it is air which is the cause for this difference in the time of fall of a feather and a stone, we should perform the experiment at a place where there is no air. Surface of the moon can be one possibility. However, on the earth's surface there is no such natural place. But we can create such a situation in a special large tube by evacuating* as much air from it as is possible.

Now if we can manage to drop a feather and a stone simultaneously in such a tube, these will strike the base together, i.e., the time taken by the feather to fall through the given length of the tube will be the same as that of any heavy body falling through the same height. Thus, by taking into account the resistance due to air, we can resolve the apparently confusing observation. Let us recall the various steps in this controlled experiment.

*Note that air can never be completely evacuated from any vessel

(i) We observe that different bodies when released from certain height fall towards the earth. This is a qualitative result.
(ii) When we measure the time taken by different bodies to fall through a given height, we discover that in some cases these times can be different. Now we have done a measurement We have a quantitative result that there is a difference between the times taken by different bodies to fall through the same height.
(iii) The next step is to check this result with existing theory.
(iv) We find a disagreement between theory and experiment and look for possible reasons for this disagreement.
(v) We devise experiments to check our conclusions.
(vi) Such new experiments help us in our understanding of the initial observations.

This sequence of steps is followed in most scientific investigations.

Measurements play an extremely important role in scientific investigations, particularly in physics. When we want to measure a given physical quantity, we are faced with the problem of finding a suitable device with which we can carry out the measurements. Any measuring device can measure down to a certain minimum value, known as its least count. So, a given measurement is reliable within this least count. Here we will describe some devices and related simple activities. These will give you the basic idea of measurement in physics. You should carry out these activities.

I. MEASUREMENT OF LENGTH

You learnt in the chapter on Measurements that in Mechanics there are three basic physical quantities: length, mass and time. For measuring precisely these quantities various devices have been developed. We will first describe two instruments: vernier calipers and screw gauge, which are used for measuring small lengths with accuracy better than that obtained by using a metre scale.

Vernier calipers is a device which can measure lengths with an accuracy of 0.1 mm (=0.01 cm). In Fig. P. 1 is shown a vernier calipers. It consists of a fixed scale with the least count of 1 mm. Another scale, known as vernier scale (VS) moves along the fixed scale. Ten divisions of the vernier scale are equal to nine divisions of the main scale. Suppose the zero mark of the VS coincides with 2 cm mark of the fixed scale, then the 10th mark of the vernier scale will coincide with 2.9 cm (Fig. P.2). You can check this for yourself. So, on the vernier scale 9 mm are divided into 10 divisions, i.e.

$$1 \text{ vernier scale division} = 9 \text{ mm}/10 = 0.9 \text{ mm}$$

Hence, each division on the VS is 0.1 mm less than a division on the main scale.

If we consider, say 3 divisions on the vernier scale, these will be 0.3 mm short of 3 mm.

If we now move the zero-mark of the vernier scale beyond 2.0 cm mark on the main scale by 0.3 mm (= 0.03 cm), you can check that the third mark on the VS will coincide with the 2.3 cm mark on the main scale (Fig P.3). Hence the vernier reading will be 0.03 cm and the total reading will be 2.03 cm.

Now let us consider a situation shown in Fig. P.4. The zero-mark of vernier scale is between 3.4 and 3.5 mark. Hence the length of the object will be between 3.4 and 3.5 cm. We now examine the vernier scale and see that its sixth mark coincides with a mark of the main scale. This means that the zero of the VS must have moved $0.01 \text{ cm} \times 6 = 0.06$ cm beyond 3.4 mark.

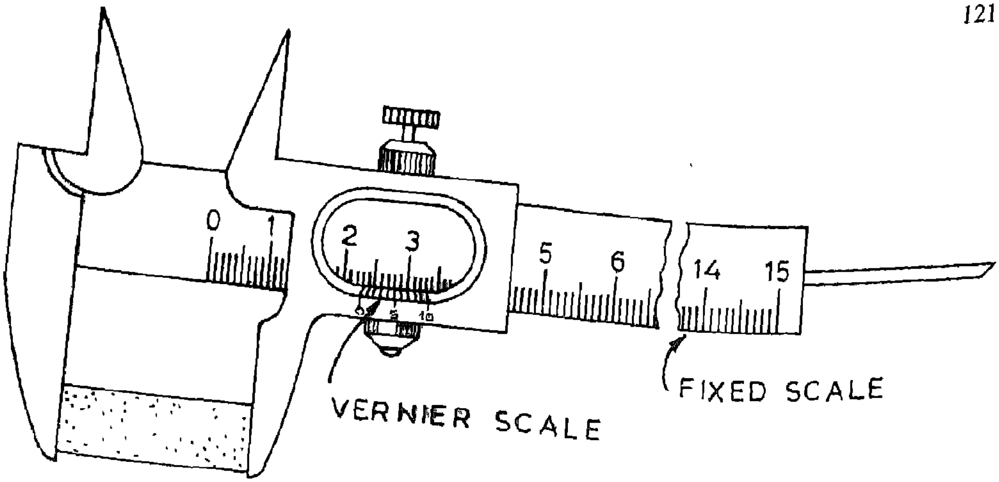


Fig. P.1

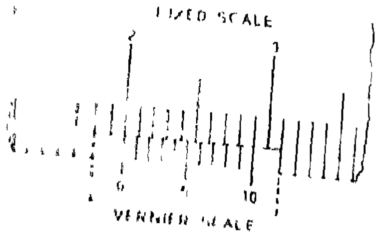


Fig. P.2

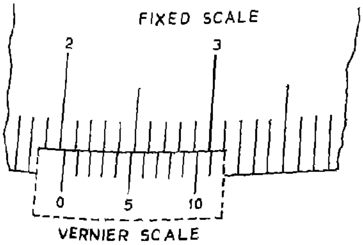


Fig. P.3

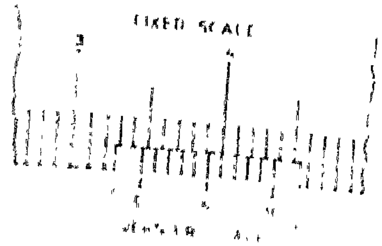


Fig. P.4

Hence, the correct thickness of the object is 3.46 cm.

When the two jaws of the vernier calipers are in contact, the zero mark of VS should coincide with the zero of the main scale. If that is not the case, the measurement has to be corrected for what is known as the zero error. The actual length of the object will be more than the measured length *if the zero of the VS lies towards the left of the zero of the main scale.* The *zero error is negative* and the reading of the calipers would be short by this amount (Fig. P.5 b). To obtain the correct length we must apply correction by adding the amount by which the zero of the VS is short of the zero of the main scale. On the other hand, *if the zero of the VS lies to the right of the zero of the main scale, the zero error is positive* (Fig. P.5-a) and must be subtracted from the observed value to obtain the correct length.

* Figs. P.2 to P.5 show enlarged views

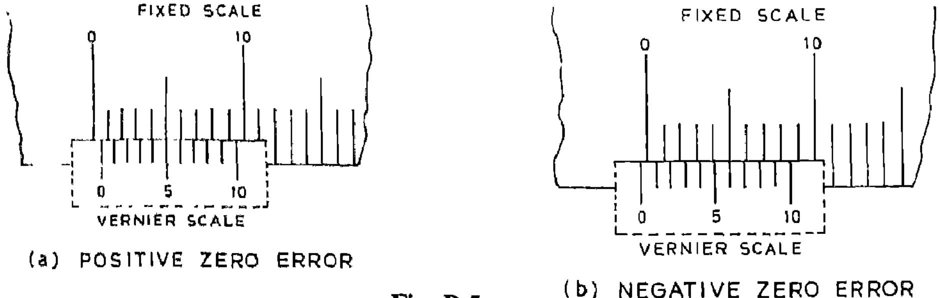


Fig. P.5

Practical Work

Apparatus needed: Metre scale, vernier calipers, some objects.

Experiment No. 1 To measure the diameter of a given spherical body, say a glass marble. Measure the diameter in at least 3 different places taking two measurements at each place Then obtain the mean diameter (up to two significant figures).

Experiment No. 2 To measure the length of a given object (3-4 cm in length) with a metre scale and with vernier calipers. Compare the two results

In measuring the length with a metre scale, place the object at different positions along the scale for every reading Take 5 readings in each case.

Experiment No. 3 Find the area of a small rectangular metallic plate. Take at least 3 readings for each side

Screw gauge is a device which can measure small lengths with accuracy down to 0.01 mm = 0.001 cm. To obtain such small least count, use is made of the fact that in one rotation of a screw the linear distance covered along its axis is small. The linear distance covered in one full rotation of the screw is called the pitch of the screw. In case of the screw gauge shown in Fig P.6, a linear distance of 1 mm is covered in one full rotation of the screw (In some screw gauges* the pitch of the screw is 0.5 mm) The full rotation is divided into 100 equal parts and, therefore, the least count of the screw gauge is

1/100 mm = 0.01 mm = 0 001 cm.

A screw gauge consists of a metal frame. At one end is a fixed solid cylinder P (Fig P-6) with plane surface projecting beyond the frame to support the body whose thickness is to be measured. In

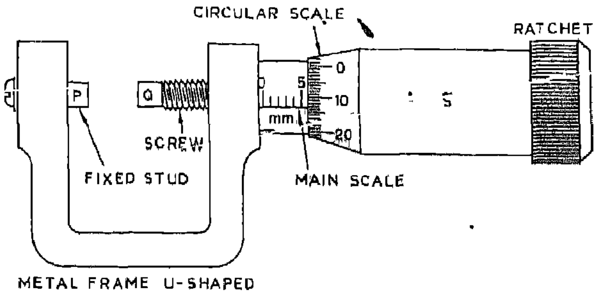


Fig. P.6

*Such screw gauges allow even higher accuracy

the front of it is a special screw. This can be moved forward or backward with respect to the frame by head S On the nut, through which the screw moves, is a scale with least count of 1 mm. On the head of the screw is a scale having 100 equal divisions. In one full rotation, the screw advances one division of the main scale. Therefore, for each division of the rotating scale the linear distance covered is 1 mm/100 = 0.01 mm or 0.001 cm. The two scales should read zero when P and Q are just touching each other.

To operate the screw gauge, we open the screw so that the distance between P and Q is greater than the thickness to be measured. This can be the diameter of a wire or thickness of metal or hard plastic sheets We hold the object close to P and move the screw so that the object is held lightly between P and Q In order to prevent the screw pressing hard on to the object, screw gauges are provided with a ratchet stop When the screw is moved with the ratchet stop, as soon as the screw Q comes in contact with the object, the ratchet stop starts moving freely and does not move the screw any further

Practical Work

Apparatus needed: Screw gauge, an office pin and thin sheets. metallic, plastic.

Experiment No. 4 To measure the diameter of a given thin wire Measure the diameter with the screw gauge at different positions and also along different diameters. Find the mean diameter by taking average of at least 3 sets of observations

Experiment No. 5 Measure the thickness of a uniform thin sheet of metal, plastic or paper. Measure the thickness at different points on the sheet and find the average thickness of the sheet

II MEASUREMENT OF VOLUME

We will now consider how the volume of a given body can be determined If a body has a simple geometrical shape (like that of a cube or a sphere, which we call regular bodies) one can easily determine its volume by using the knowledge of geometry (Table 2 1 in Chapter 2 on "Measurement") For an irregular body (having no simple geometrical shape), one must use another method to find its volume. However, in all cases volume is expressed in any one of the following units· mm^3, cm^3 or litre (= 10^3 cm^3) or in m^3.

Liquids like kerosene, petrol, milk, etc. are sold in litre and its fractions. That is, these are sold in terms of volume.

For determining the volume of a given quantity of a certain liquid, we normally use graduated containers like measuring beakers or measuring cylinders. One just pours the given liquid in such a graduated beaker or cylinder and reads the volume.

To find the volume of a small irregular body not soluble in water, we first pour some water in a graduated cylinder and note its volume We then drop the body in the cylinder Suppose the body sinks in water Then the difference in the level of the liquid, before the body is put inside and the level after it is dropped, gives us the volume of the body.

If the body floats in water, then the process is a little more involved. We take a stone or a block of metal big enough so that when the given body is tied to it and dropped inside the

cylinder, both will sink. (The size of stone or metal block must be so selected that it will easily go inside the graduated cylinder.) We then find the combined volume of the stone and the given body and also of the stone alone. Subtracting one from the other, we get the volume of the given body.

To find the volume of a given body which is bigger and will not go inside a measuring cylinder, we can use an overflow can.

Practical Work

Experiment No. 6	Find the volume of a given amount of liquid by using three measuring cylinders of different sizes.
Experiment No. 7	Find the volume of an irregular body which sinks in water, using both a graduated cylinder and an overflow can
Experiment No. 8	Find the volume of an irregular body which floats in water using both a graduated cylinder and an overflow can. Compare the two results.

III MEASUREMENT OF MASS

Mass of a body is determined by comparing it with known weights. For making the comparison in a laboratory, a physical balance is used (Fig. P 7).

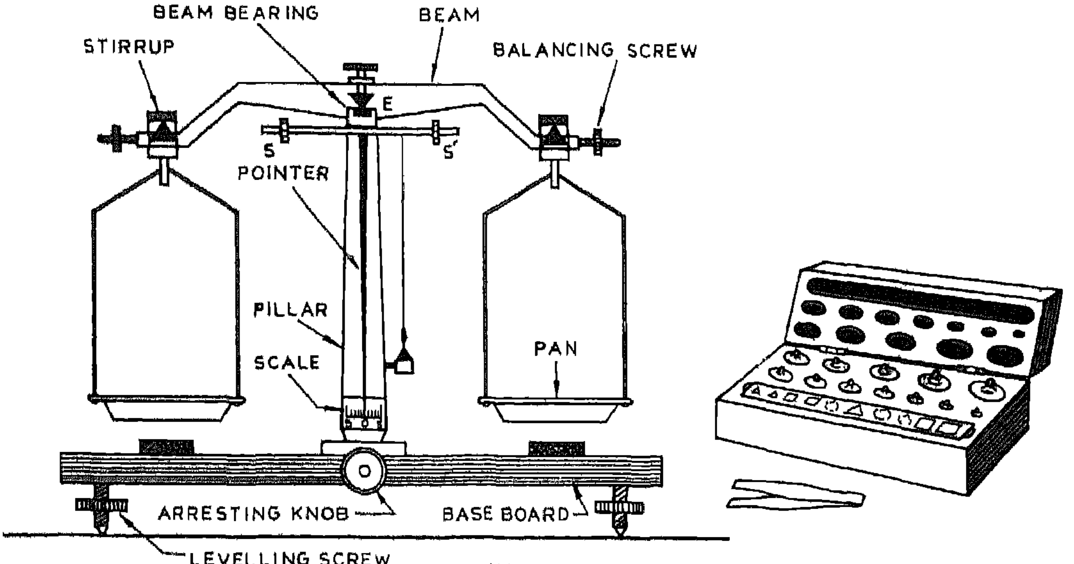


Fig. P.7

Like any ordinary balance it has two scale pans, one at each end of the beam. The beam rests on a knife edge E. When not in use, the beam is held up on supports S,S'. When we want to use it, the beam is released with the help of a knob provided in front of the balance near the base. There is a large pointer in the middle of the beam which indicates the balancing of the masses in the two scale pans. When the two masses are equal, or when the two scale pans are empty, the pointer comes to rest at the zero mark on the small scale fixed just behind the

pointer, or it oscillates equally on the two sides of this zero mark. When the masses are unequal, the pointer moves more towards the lighter side

The solid body, whose mass is to be determined, is placed on the left scale pan. The pointer then swings to the right. With the help of a clean forceps weights are put on the right scale pan, starting from large weights. The weights are slowly decreased until the pointer returns to the zero on the scale. The weights kept on the right-hand pan are then noted. When these weights are added together, it gives the mass of the body. If the body happens to be of small mass, one has to use weights down to a few milligrams

When the mass of a given quantity of a liquid is to be determined, the experiments involve two parts We first weigh a clean empty glass beaker or flask. Then the liquid is poured into this container. The mass of the liquid and the container is then again determined. The mass of the container is subtracted from the combined mass of container and the liquid, giving us the mass of the liquid.

Practical Work

Apparatus needed:	Physical balance, beaker, a few solid bodies and water
Experiment No. 9	Determine the masses of three different given solid bodies.
Experiment No. 10	Determine the masses of different quantities of liquids.

IV. DETERMINING DENSITY

Given a body, we can measure its mass as well as its volume. Knowing these, we can determine another important physical quantity - the density. Density of a given body is defined as mass contained in a unit volume. That is, if M kg is the mass of a body whose volume is V m^3, its density ρ is given by:

$$\rho = \frac{M}{V} \quad \text{kg/m}^3.$$

Given a material, its density is fixed, whatever its mass For example, a spherical ball and a cube made from the same material, say iron, will have the same density Pure iron has a characteristic density. Thus, the concept of density can be used to characterise materials. Bodies, even of identical shape, made of different materials will have different densities. The density of a material will change if we add some other substance to it, as in metals.

Like a solid, a liquid also has a characteristic density. Any addition to a given liquid can be detected by measuring the density of the liquid. We can say that if the measured density of a liquid differs from that of the pure liquid, then something must have been added to the liquid.

Practical Work

Apparatus needed:	Physical balance, graduated jar or overflow can, two given solid bodies, liquid and mixtures whose densities are to be determined.

Experiment No. 11 Determine the densities of two given solid bodies

Experiment No. 12 Determine the density of a given liquid.

Experiment No. 13 Study the variation in the density of water by adding known amounts (say 5 g, 10 g and 15 g) of common salt in 100 ml of water.

V. MEASUREMENT OF TIME PERIOD OF A PENDULUM

A simple pendulum consists of a *bob*, i.e., a small heavy solid sphere of metal, tied to one end of a light, strong string. You can take a metre length of a good sewing thread and tie one end of the thread to the hook of the bob. Suspend the bob from the other end of the thread to a rigid support, as shown in Fig. P.8. The point from where the bob is suspended is called the *point of suspension*. The length measured from the point of suspension to the centre of the bob is called the *length of the pendulum*.

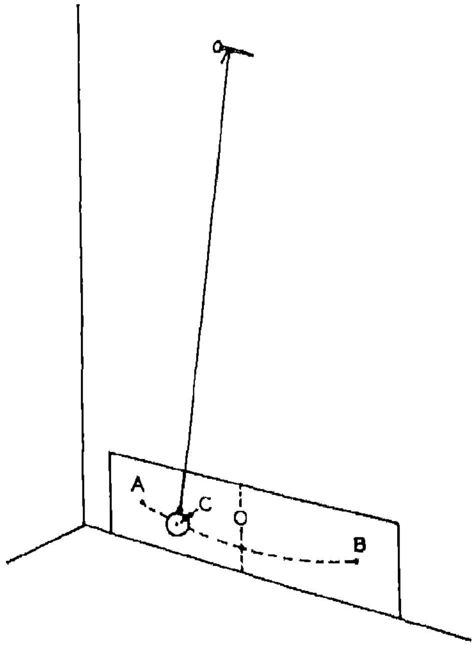


Fig. P.8

Let the bob stand for some time so that it becomes stationary. Pull it a little on one side and release it. Once it is released, the bob starts oscillating. Starting from A, it moves towards O. On passing through O, it goes to B and from there returns towards O. It passes through O and reaches A again. The bob is said to have moved through one complete oscillation when starting from A, it returns to A, or *after passing through O, it returns to O in the same direction of motion.* The distance from O, the central point of motion, to A or to B (the two being equal) is called the *amplitude of oscillation.*

Due to air resistance, the amplitude of oscillation of your pendulum will gradually decrease and the bob will ultimately come to a stop. However, it has been observed that this does not make much difference in the time it takes to complete one oscillation. This time is called *time period* of the pendulum. Time period of a simple pendulum remains the same, whatever its amplitude, provided it is not too large. This fact was first discovered by Galileo (1564-1642). He observed that a chandelier hanging in a cathedral always took the same time to complete one oscillation irrespective of the amplitude of the swing. (He measured the time of oscillation in terms of his pulse.) It is this discovery that led to the invention of pendulum clocks.

With a stop-watch, you can measure the time period of a pendulum. This can be done conveniently by placing a white card with a straight vertical line drawn on it, behind the

pendulum such that the thread is along the line when the pendulum is at rest Set the pendulum in motion. Start the stop-watch when the bob moves across the line on the card from, say, left to right. *When the bob crosses the line again from left to right* the bob has completed one oscillation. Since the time period of your pendulum will be quite small, you shouldobserve the time interval for a number of oscillations (say 20 to 50) and then determine the time period of a single oscillation by dividing the measured time by the number of oscillations.

Practical Work

Apparatus needed:	A simple pendulum, stop-watch/stop-clock and metre rod/half-metre rod.
Experiment No. 14	Determine the time period of a simple pendulum by measuring the time of 3, 5, 10, 20, 40 oscillations Compare the values of time period obtained by each measurement.
Experiment No. 15	Study the variation of time period with amplitude of oscillations. Take four different values of the amplitude. Take 50 oscillations in each case.
Experiment No. 16	Determine the time period of a simple pendulum for four different lengths (Take 20 oscillations in each case.) Plot a graph between T^2 and l.

VI. MEASUREMENT OF WEIGHT

The weight of a body is the force with which the earth pulls the body towards its centre If m is its mass, then mg newton is the *weight* of a body of mass m kg.

One method of finding weight of a body is to find its mass using a physical balance and then multiply this with $g\,(=9.8\ \mathrm{m/s^2})$. If we look more closely at the experiment, we find that the two weight forces (due to the masses placed in the two pans) are not acting at the same point but at two different points, that is, the points from where the two pans are suspended from the beam. Thus in such a balance, use is made of principle of moments, i.e., we balance the moment of the forces at two different points on the beam. Since the two points where the weight forces are acting are equidistant from the middle point, about which the balance-beam rotates, the experiment gives directly the weight of the unknown body in terms of the known weights.

We can also use unequal force arms to determine the weight of a body. We suspend a metre scale from the centre and hang the body of weight W, say, at a convenient mark on one side of the scale. Let its distance from the centre be l. Then take a known weight, suspend it on the other side of the centre and move it along the scale till the scale becomes horizontal. If M is the known mass and it is suspended at a distance l' from the centre. then according to eq. 5.11

$$W \times l = Mg \times l'$$

or

$$W = Mg \times \frac{l'}{l}$$

We can also balance the unknown weight by suspending two masses M_1 and M_2 on the other side of the metre rod. To obtain equilibrium it is convenient to fix one mass, say M_1, at

some convenient distance l_1 from the centre and move mass M_2 till equilibrium is reached (Fig. P.9). Let the distance of mass M_2 at equilibrium be l_2. Then

$$W \times l = M_1 g\, l_1 + M_2 g\, l_2$$

or

$$W = \frac{(M_1\, l_1 + M_2\, l_2)\, g}{l}$$

Another method is to use a spring balance. In the spring balance, there is a hook with which the body to be weighed is attached, as shown in Fig P.10. There is a pointer which moves along the scale and shows the weight of the body. When nothing is attached to the hook, the pointer reads zero. Unlike a physical balance a spring balance is a direct method for determining the weight of a body, since the extension of the spring is directly dependent on the force applied

We may note that most spring balances are calibrated in kilogram (or gram) rather than in newton. This is because they are also used to weigh various objects.

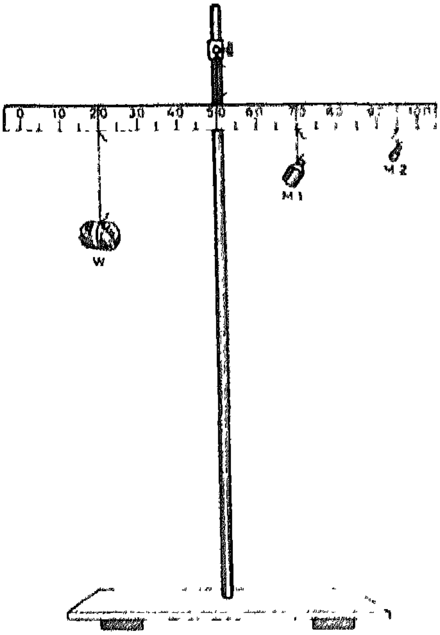


Fig. P.9

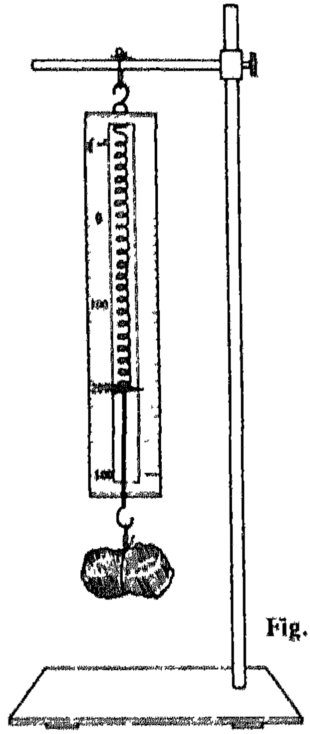


Fig. P.10

Practical Work

Apparatus needed: Spring balance, weight box, thread, metre rod, wedge, some solid bodies whose weights are to be determined, known weights from weight box.

Experiment No. 17 Determine the weights of five given solid bodies using a spring balance.

Experiment No. 18 Determine the weight of a given body using the principle of moments by

using (a) one known mass; (b) two known masses. Also weigh it using a spring balance and compare the weights.

VII DETERMINING THE C.G OF A LAMINA

Newton's law of gravitation states that the force of gravity is proportional to the product of the masses and inversely proportional to the square of the distance between them. For an extended body like the sun or the earth or the table or the glass placed on it, from where does one measure these distances?

For every extended object *there exists one point* such that when the object is attracted by the earth, it behaves as if its entire mass was concentrated at this point. This point is called the *centre of gravity* (abbreviated as C.G.) of the body. For example, in the case of a uniform spherical object, the centre of gravity of the body is at the centre of the sphere. But the C.G. of a uniform circular ring lies outside the material of the ring. It is at its centre.

We will consider here how the centre of gravity of an irregular cardboard can be determined.

Make a number of small holes (4 to 5) near the boundary of the cardboard. Suspend the cardboard from one of the holes from a stand, as shown in Fig. P.11. Allow a plumb line to fall from the stand such that it lies close to the hole from which the cardboard has been suspended. Make a few pencil marks on the cardboard along the plumb line. Remove the cardboard from the stand and join the points. Now suspend the cardboard from the stand from some other hole and repeat the process. Do this for all holes. You will find that all the lines intersect at almost one point. This point is the centre of gravity of the body. You can test this easily. If you have done it correctly, the cardboard will balance on the tip of a pin at this point. You cannot balance the cardboard at any other point.

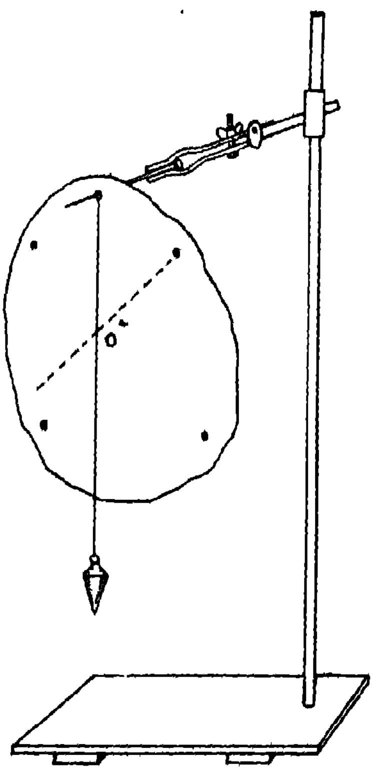


Fig. P.11

Practical Work

Apparatus needed: An irregular plane cardboard, stand, a plumb line.

Experiment No. 19 Determine the centre of gravity of a given irregular plane sheet.

VIII. DETERMINING THE SPECIFIC HEAT OF A BODY

We learnt in the chapter on 'Heat' that heat is exchanged between two bodies having different temperatures when they are brought in contact. The body at the lower temperature

gains heat while the body at the higher temperature loses it. The exchange of heat continues till thermal equilibrium is reached, i.e., till both the bodies attain the same equilibrium temperature T_e, given by equation 8.3. We can easily measure temperature and mass with the help of thermometer and balance, respectively. If we know the specific heat of one body, we can easily determine the specific heat of the other body, using the equation 8.4.

Practical Work

Apparatus needed: A glass tumbler, thermometer (having the range 0-100° C), a beaker of 1000 ml capacity, heater to heat water in the beaker, a stirrer.

Experiment No. 20 Estimate the specific heat of glass.

Weigh the glass tumbler. Note the room temperature. It would also be the temperature of the glass tumbler. Heat the water in the beaker to about 70° C. Remove the beaker from the heater and note the temperature of water with the help of thermometer. Pour the heated water in the glass tumbler and fill 3/4th of it. Keep stirring with stirrer for half a minute and then note the temperature T_e of water in the glass tumbler. Determine mass of the filled tumbler and hence of water contained in it.

Making use of equation 8.4, determine specific heat of the glass tumber (the specific heat of water = 4.2×10^3 J/kg° C). Repeat the experiment by heating water up to 85°C. Determine the mean value of the specific heat of glass.

Apparatus needed: A flask of 1 litre capacity, a thermometer (0-100° C), a stop-watch/stop-clock, a stand to fix the thermometer.

Experiment No. 21 Study the rate of cooling of a given mass of heated water.

Fill the flask almost up to its neck. Heat it till water in the flask is at about 80° C. Allow it to cool and note down the temperature of the water every minute for first five minutes and then after every two minutes (Fig. P.12). Plot a graph between the temperature and the time.

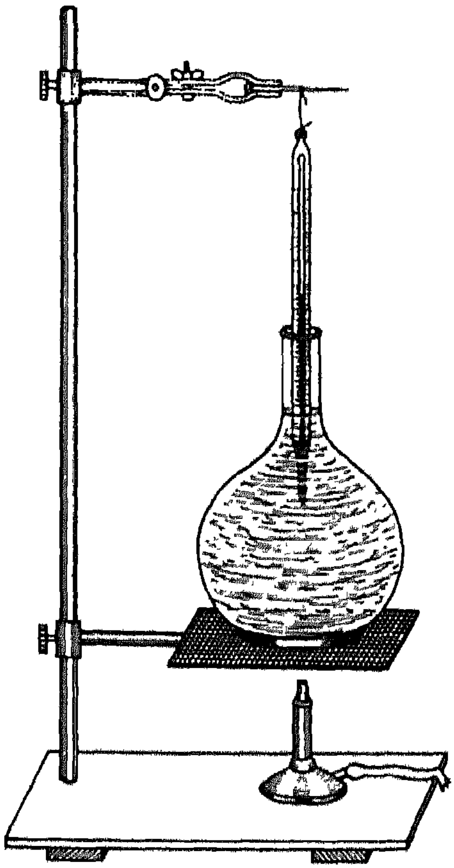


Fig. P.12

Repeat the experiment by heating water to 70° C and 90° C.

Apparatus needed: A beaker of 1 litre capacity, a thermometer (0-100° C) and a stop-watch/stop-clock

Experiment No. 22 Estimate the rate of supply of heat by a heater

Fill the beaker (about ¾th of its capacity) with water. Note the temperature of the water in the flask. Start heating the flask. As soon as the temperature of the water indicated by the thermometer reaches some value, say 30° C, start the stop-watch Note down the time taken when the temperature reaches 40° C, 50° C, 60° C, 70° C and 80° C. From the observations, calculate the rate of heat supplied by the heater.

IX. DETERMINING RELATIVE HUMIDITY

We have learnt in Chapter 8 that water vapour are always present in the atmospheric air. The water vapour in air at any given time are measured in terms of relative humidity. The relative humidity is defined as the ratio, expressed in percentage, of water vapour actually present in 1 m^3 of air at a particular temperature to the total quantity of water required to saturate the same volume of air at that temperature.

In practice, however, direct measurement of the amount of water vapour present in the air is rather difficult. Therefore, indirect methods are employed to determine relative humidity. The devices used to measure relative humidity are called hygrometers. Various types of hygrometers are used for measuring relative humidity. Some hygrometers depend on hygroscopic properties (properties dependent on humidity) of hair or thin strip of an appropriate material. The relative humidity is determined by measuring the change in length of the hair (or the thin strip) which takes place with the change in humidity (moisture content) of the air However, this type of hygrometer is not very accurate

In school laboratory, relative humidity can be measured with the help of a very simple device called dry and wet bulb hygrometer (Fig. P.13). It consists of two thermometers. One of the thermometers reads actual temperature of the atmospheric air and is called *dry-bulb thermometer*. The bulb of the second thermometer is covered with a wet cloth. This is called the *wet-bulb thermometer*. This thermometer reads a temperature which depends on the rate of evaporation of water around the outer surface of the bulb. If the air is saturated, there would be no evaporation of water and so the wet bulb will show the same temperature as the dry bulb. On the other hand, if the air is not saturated, evaporation of water will take place from the wet cloth. As a result of the evaporation (because latent heat of evaporation would be taken from the wet bulb), the wet-bulb thermometer will show a lower temperature.

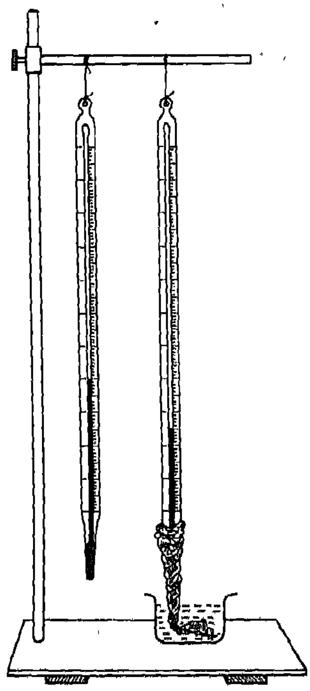


Fig. P.13

Drier the air, greater the evaporation from the wet bulb and lower the temperature indicated by that thermometer. To facilitate evaporation, often the wet-bulb thermometer is fixed on a stand and rotated for 2-3 minutes till it shows a steady temperature Same effect can also be obtained by using a hand fan around the wet-bulb thermometer. Since the steady temperature shown by the wet bulb is linked with the humidity of the air, tables showing the relative humidity in terms of the readings of the two thermometers have been prepared. Thus, once we know the air temperature and the depression in the wet-bulb thermometer, we can determine the relative humidity from the table given here.

Practical Work

Apparatus needed: Two thermometers, a piece of cloth, hand fan and stand.

Experiment No. 23 Determine the relative humidity of air and state all the reasons for differences in temperatures shown by the two thermometers.

Relative Humidity Value (Per Cent) at 1000 millibar

Dry bulb temperature in° C	Depression of Wet Bulb in ° C																
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°
46°	94%	89%	83%	78%	73%	68%	64%	59%	55%	51%	47%	43%	40%	31%	33%	29%	26%
44°	94%	88%	83%	78%	72%	68%	63%	58%	54%	50%	46%	42%	38%	34%	31%	27%	24%
42°	94%	88%	82%	77%	72%	67%	62%	57%	53%	48%	44%	40%	36%	32%	29%	25%	22%
40°	94%	88%	82%	76%	71%	66%	61%	56%	51%	47%	42%	38%	34%	30%	26%	23%	19%
38°	94%	87%	81%	75%	70%	65%	59%	54%	50%	45%	41%	36%	32%	28%	24%	21%	17%
36°	93%	87%	81%	75%	69%	63%	58%	53%	48%	43%	39%	34%	30%	26%	22%	18%	14%
34°	93%	86%	80%	74%	68%	62%	56%	51%	46%	41%	36%	32%	27%	23%	19%	15%	11%
32°	93%	86%	79%	73%	67%	61%	55%	49%	44%	39%	34%	29%	24%	20%	16%	11%	7%
30°	93%	85%	78%	72%	65%	59%	53%	47%	42%	36%	31%	26%	21%	16%	12%	8%	3%
28°	92%	85%	77%	70%	64%	57%	51%	45%	39%	33%	28%	23%	18%	13%	8%	3%	
26°	92%	84%	76%	69%	62%	55%	49%	42%	36%	30%	25%	19%	14%	8%	3%		
24°	91%	83%	75%	68%	60%	53%	46%	39%	33%	27%	21%	15%	9%	4%			
22°	91%	82%	74%	66%	58%	51%	43%	36%	29%	23%	16%	10%	4%				
20°	91%	81%	73%	64%	56%	48%	40%	33%	25%	18%	11%	5%					
18°	90%	80%	71%	62%	53%	45%	36%	29%	21%	13%	6%						
16°	89%	79%	69%	60%	50%	41%	32%	24%	16%	7%							
14°	89%	78%	67%	57%	47%	37%	28%	18%	10%	1%							
12°	88%	76%	65%	54%	43%	32%	22%	12%	3%								
10°	87%	74%	62%	50%	38%	27%	16%	5%									
8°	86%	72%	59%	46%	33%	21%	9%										
6°	85%	70%	55%	41%	28%	14%											
4°	83%	67%	51%	36%													
2°	82%	64%															

APPENDICES

APPENDIX A

THE GREEK ALPHABET

Symbol	Pronunciation	Symbol	Pronunciation
α	Alpha	ν	Nu
β	Beta	ξ	Xi
γ	Gamma	o	Omicron
δ	Delta	π	Pi
ϵ	Epsilon	ρ	Rho
ζ	Zeta	σ	Sigma
η	Eta	τ	Tau
θ	Theta	υ	Upsilon
ι	Iota	ϕ	Phi
κ	Kappa	χ	Chi
λ	Lambda	ψ	Psi
μ	Mu	ω	Omega

APPENDIX B

UNITS OF PHYSICAL QUANTITIES

Name	*Abbreviation*	*Remarks*
I. Length		
metre	m	standard
kilometre	km	km = 10^{3}m
centimetre	cm	cm = 10^{-2}m
millimetre	mm	mm = 10^{-3}m.
II. Mass		
kilogram	kg	standard
gram	g	g = 10^{-3}kg
milligram	mg	mg = 10^{-6}kg
III. Time		
second	s	
minute	min	min = 60 s
hour	h	h = 3,600 s
IV. Area		
square metre	m^2	
square centimetre	cm^2	$cm^2 = 10^{-4}m^2$
square millimetre	mm^2	$mm^2 = 10^{-6}m^2$
V. Volume		
cubic metre	m^3	
cubic centimetre	cm^3	$cm^3 = 10^{-6}m^3$
cubic millimetre	mm^3	$mm^3 = 10^{-9}m^3$
litre	l	$l = 10^{-3}m^3$
VI. Density		
kilogram per metre cube	kg/m^3	
gram per cubic centimetre	g/cm^3	$g/cm^3 = 10^3\ kg/m^3$
VII. Velocity		
metre per second	m/s	
centimetre per second	cm/s	cm/s = 10^{-2}m/s
kilometre per hour	km/h	km/h = $\frac{1}{3.6}$ m/s
VIII. Acceleration		
metre per second square	m/s^2	
centimetre per second square	cm/s^2	$cm/s^2 = 10^{-2}m/s^2$
IX. Angular velocity		
radians per second	(rad/s); $\frac{1}{s}$*	

*Since angle is measured as a ratio, the unit of angular velocity is usually taken as s^{-1}.

APPENDIX C

TRIGONOMETRIC FUNCTIONS

Consider a right-angled triangle ABC (Fig. C.1). Let θ be the angle that the hypotenuse AC makes with the base AB. We define the following trigonometric functions.

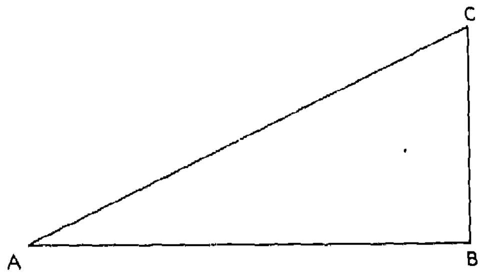


Fig. C.1: *Right-angled triangle ABC.*

(i) sine θ , abbreviated as sin θ:

$$\sin\,\theta = \frac{\text{perpendicular}}{\text{hypotenuse}} = \frac{BC}{AC}$$

(ii) cosine θ , abbreviated as cos θ:

$$\cos\,\theta = \frac{\text{base}}{\text{hypotenuse}} = \frac{AB}{AC}$$

(iii) tangent θ, abbreviated as tan θ.

$$\tan\,\theta = \frac{\text{perpendicular}}{\text{base}} = \frac{BC}{AB}$$

We further note that

$$\tan\,\theta = \frac{BC}{AB} = \frac{BC}{AC} \quad \frac{AC}{AB} = \frac{\sin\,\theta}{\cos\,\theta}$$

Also, since for this right-angled triangle

$$(AB)^2 + (BC)^2 = (AC)^2$$

We obtain on dividing both sides by $(AC)^2$

$$\left[\frac{AB}{AC}\right]^2 + \left[\frac{BC}{AC}\right]^2 = 1$$

or $\quad \cos^2\theta + \sin^2\theta = 1$

Given the value of any of the ratios: $\frac{AB}{AC}$ or $\frac{BC}{AB}$ or $\frac{BC}{AC}$

we can find the angle θ from the table of trigonometric functions. Values of these

functions for a few values of the a[illegible] are given below:

Functions \ θ	$0°$	$30°$	$45°$	$60°$	$90°$
$\sin\theta$	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1
$\cos\theta$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0
$\tan\theta$	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞

Note that $\sqrt{2} = 1.414$, $\sqrt{3} = 1.732$ $1/\sqrt{2} = 0.707$ and $1/\sqrt{3} = 0.577$

We extend the base AB to any length AB′ and at B′ draw a perpendicular parallel to BC. It will cut the line AC produced, at some point C′ (Fig. C.2). We thus get a new right-angled triangle AB′C′ The bigger triangle AB′C′ is similar to the triangle ABC. By the property of similar triangles we know that

$$\frac{AB}{AB'} = \frac{AC}{AC'} = \frac{BC}{B'C'}$$

From these equalities, we get

$$\frac{BC}{AC} = \frac{B'C'}{AC'} \; ; \; \frac{AB}{AC} = \frac{AB'}{AC'} \; ; \; \frac{BC}{AB} = \frac{B'C'}{AB'}$$

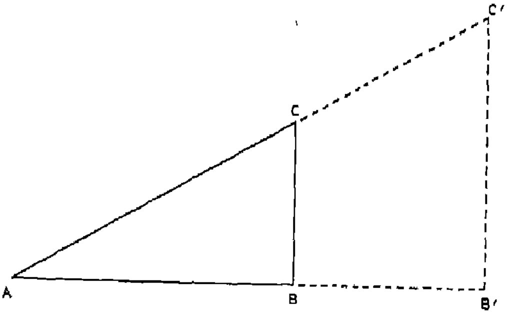


Fig. C.2: *Extension of sides of the triangle gives us a similar right-angled triangle.*

From this, it follows that for a given angle θ, the ratios $\frac{BC}{AC}, \frac{AB}{AC}$ and $\frac{BC}{AB}$ and hence the functions $\sin\theta$, $\cos\theta$ and $\tan\theta$ are independent of the length of the base (AB) of the right-angled triangle.